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Strategies for Adopting Additive Manufacturing Technology Into Business Models

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College of Management and Technology

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Robert Martens

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Walden University
2018

Abstract

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by

Robert Martens

MS, University of Glamorgan, 2007

MBA, Keele University, 2006

Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Business Administration

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August 2018

Abstract

Additive manufacturing (AM), also called 3-dimensional printing (3DP), emerged as a disruptive technology affecting multiple organizations' business models and supply chains and endangering incumbents' financial health, or even rendering them obsolete. The world market for products created by AM has increased more than 25% year over year. Using Christensen's theory of disruptive innovation as a conceptual framework, the purpose of this multiple case study was to explore the successful strategies that 4 individual managers, 1 at each of 4 different light and high-tech manufacturing companies in the Netherlands, used to adopt AM technology into their business models. Participant firms originated from 3 provinces and included a value-added logistics service provider and 3 machine shops serving various industries, including the automotive and medical sectors. Data were collected through semistructured interviews, member checking, and analysis of company documents that provided information about the adoption of 3DP into business models. Using Yin's 5-step data analysis approach, data were compiled, disassembled, reassembled, interpreted, and concluded until 3 major themes emerged: identify business opportunities for AM technology, experiment with AM technology, and embed AM technology. Because of the design freedom the use of AM enables, in combination with its environmental efficiency, the implications for positive social change include possibilities for increasing local employment, improving the environment, and enhancing healthcare for the prosperity of local and global citizens by providing potential solutions that managers could use to deploy AM technology.

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Dedication

I dedicate this work to my family, who believed in me during this quest. In particular, I wish to thank my father, Dominicus Martens, for telling me about the many journeys he made across the world, for giving me the appreciation for mechanical engineering and procurement, and for showing me technology and business go well together. To my mother, Cornelia, for gifting me with stamina, and an inquisitive and critical mind. I want to thank my wife, Lu Dongmei, for her constant encouragement during this research and belief in my abilities to achieve this goal. To my children Niek, Louis, Max, and Franc: thanks for your support along this journey; I hope I have shown you the importance of goal setting and dedication. Never stop learning.

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Section 1: Foundation of the Study

Additive manufacturing (AM) is an innovative production technology for building up items layer by layer. The common name is three-dimensional printing (3DP; Gibson, Rosen, & Stucker, 2015). Modern technologies have often disrupted existing business models, causing leading companies to become obsolete (Christensen, 2016). Amshoff, Dülme, Echterfeld, and Gausemeier (2015); Bogers, Hadar, and Bilberg (2016); and D'Aveni (2015) considered AM a disruptive innovation. Business leaders should be aware of disruptive threats to their firms. This study was about successful strategies that managers who understood the threats and opportunities of AM used to adopt this disruptive technology into their business models.

Background of the Problem

Hull (2015) invented AM in 1983. In the United States, the automotive and aviation industries were early adopters of this innovative technology. After essential patents expired in the 2000s, additional companies selling AM equipment emerged rapidly (Yeh, 2014). The first service companies began offering 3D printed products, making the technology more mainstream (Hull, 2015). More industries started to use this technology, such as the dental, hearing implants, jewelry, power, aviation, space, and the consumer goods sector (Hull, 2015). AM technology builds items layer by layer, thereby enabling design freedom and supporting the production of customized products in small series (Gibson et al., 2015). The decoupling of design and manufacturing also allows product developers to modify an item's design during production (Pour, Zanardini, Bacchetti, & Zanoni, 2016). Uncoupling design and production enables local production that may lead to the rise of advanced business models and supply chains. Products made using AM may be lighter or even stronger than products created with traditional manufacturing processes (Thomas & Gilbert, 2014). Moreover, items produced with AM enhance sustainability (Mani, Lyons, & Gupta, 2014; Thiesse et al., 2015) as they can be designed lighter, produced locally, and require fewer natural resources (Despeisse & Ford, 2015). These phenomena have the characteristics of a disruptive innovation. Such innovations affect existing marketplaces but also offer new opportunities through innovative business models (Amshoff et al., 2015).

Problem Statement

AM emerged as a disruptive technology affecting multiple organizations' business models and supply chains, threatening incumbent businesses' health or even that they may become obsolete (Bogers et al., 2016; Fawcett & Waller, 2014). This threat is increasing significantly because the world market for products created by AM has grown more than 25% each year over the last 25 years and will likely increase from 2.43 billion Euro in 2013 to more than 10 billion Euro in 2018 (Fornea & van Laere, 2015). The general business problem was that managers often fail to adapt to disruptive innovations, such as AM, which may result in threats to the existence of their organizations. The specific business problem was that some light and high-tech manufacturing firm managers lack strategies to adopt AM technology into their business models.

Purpose Statement

The purpose of this multiple case study was to explore strategies that light and high-tech manufacturing firm managers used to adopt AM technology into their business models. The target population included four individual managers, one at each of four different light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. The findings of the study may provide positive social change to business managers by providing strategies to grow their companies, which may lead to increased local employment and a more prosperous business community.

Nature of the Study

The three research methods available are qualitative, quantitative, and the mixed method (Salvador, 2016). When conducting quantitative research, scholars attempt to explain a phenomenon based on numerical data. Quantitative research tests hypotheses (Eisenhardt, Graebner, & Sonenshein, 2016). Mixed method entails aspects of both qualitative and quantitative research (Joslin & Müller, 2016). I did not choose a quantitative or mixed-method approach because I did not test hypotheses about the relationships or differences among variables. Qualitative research is a method that includes open-ended questions to discover what is occurring or has occurred (Yin, 2011). I selected a qualitative research method because I attempted to answer *how* or *what* questions on what occurred.

I considered four research designs: (a) case study, (b) ethnography, (c) phenomenology, and (d) narrative study. Case study researchers study a contemporary phenomenon in its real life setting (Yin, 2014). I selected a case study because I explored a phenomenon within the context existing in real life. Other possible research designs for a qualitative study were ethnography, phenomenology, or narrative inquiry (Moustakas, 1994; Yilmaz, 2013). Ethnography involves direct observation of cultural subjects in the field (Moustakas, 1994). When using phenomenology, the researcher seeks to explore the meanings of a group of people's lived experiences with a certain phenomenon (Moustakas, 1994), and with narrative inquiry, a researcher aims to study individuals' experience with a phenomenon by collecting their stories (Bevan, 2014). Ethnography was not an appropriate research design for my study because I was not studying the culture of subjects. Phenomenology was not suitable for this study as I was neither studying events nor lived experiences of participants. Narrative inquiry was not appropriate for this study either as I did not collect narrative accounts or stories.

Research Question

The following research question (RQ) was the basis of this study: What strategies did light and high-tech manufacturing firm managers use to adopt AM technology into their business models?

Interview Questions

1. How did additive manufacturing technology enable new opportunities for your business?
2. What alternative strategies did you consider when you were confronted with the emergence of additive manufacturing?
3. How were your suppliers' additive manufacturing capabilities of influence on your decisions?
4. How did the emergence of additive manufacturing affect your firm's existing business model?

5. What strategies has your organization developed to adopt additive manufacturing in your business model?
6. What strategic considerations did you have for establishing or not establishing a separate business unit to operate additive manufacturing?
7. What additional information would you like to share about strategies for adopting additive manufacturing?

Conceptual Framework

In 1997, Christensen introduced the *disruptive technology* theory, later relabeled the *disruptive innovation* theory (Christensen, 2006). In this theory, Christensen (2016) described a process where at first people use innovative products or services in uncomplicated situations outside the mainstream application. Next, the disruptive innovators take over the existing market and, in the end, force incumbent companies out (Christensen, 2016). Often, disruptive technologies initially perform less well than the current ones (Christensen, 2016).

Novel technologies attract first users because of their different features, such as a more natural use or being more convenient, cheaper, smaller, or more flexible than existing technologies (Christensen, 2016). Usually, incumbent firms' most profitable clients are initially not interested in these innovations; so, as a result, disrupters can test their innovative technologies in smaller markets that existing companies tend to ignore (Christensen, 2016).

Slowly, the novel technology improves, in performance or price, until demands of the mainstream marketplace are met; this is the moment the disruptive technology supplants the most prevalent one, and new firms replace nonadapting companies (Christensen, 2016). The emergence of AM technology shows a similar pattern to that covered in the theory of disruptive innovation (Bogers et al., 2016). Therefore, this theory was a lens for understanding the findings from this study.

Operational Definitions

The below-listed terms are used in this study, and their meanings are as follows:

Additive manufacturing (AM): Additive manufacturing is the official term given by the American Society for Testing and Materials (ASTM) for a manufacturing process that adds materials layer by layer, directly from a computer model. This process enables the production of three-dimensional items, which otherwise could not be produced using conventional subtractive or formative manufacturing processes, such as machining, molding, or casting (Conner et al., 2014).

Disruptive technology: Disruptive technology is the term used by Christensen (2006) to define an initially underperforming technology that slowly influences the way companies conduct their business and ultimately displaces them.

Rapid prototyping: Rapid prototyping (RP) is the historical term used to refer to AM, which is a process mainly used to manufacture industrial prototypes, the originally indented use of AM (Gibson et al., 2015).

Stereolithography: Stereolithography is a form of AM based on ink-jet printing techniques invented by Hull, further developed by the American company 3D Systems (Hull, 2015).

3D printing (3DP): The popular name of AM is 3D printing. Initially, MIT researchers who developed a process of AM based on ink-jet printing techniques used this term (Gibson et al., 2015).

Assumptions, Limitations, and Delimitations

All researchers should be aware of their research methods paradigm, their assumptions, and the limitations forming the basis of their investigations and supporting their conclusions (Kirkwood & Price, 2015). Furthermore, researchers need to limit the boundaries of their study to a manageable scope, although this may pose a challenge when conducting an exploratory case study (Collis & Hussey, 2014).

Assumptions

Assumptions are researchers' fundamental viewpoints that are difficult to prove (Probst & Berenson, 2014). The first assumption for this study was that the participants that I selected for this study used successful strategies to adopt AM technology. The second assumption was that the participants answered the interview questions honestly and to the best of their knowledge. The third assumption was that the participants understood the interview questions.

Limitations

All studies have constraints, but researchers should identify the particular limitations related to their research topic (Connelly, 2013). A restriction for this study was the sample size and selection of the participating companies. My lack of experience with conducting interviews was another limitation.

Delimitations

Delimitations relate to the scope of a study (Collis & Hussey, 2014). The boundaries of this study were light and high-tech manufacturing companies based in the Netherlands. In addition, various service companies using AM exist, but as they are new businesses, instead of existing firms that made a strategic choice to implement AM, I excluded these service companies from my research. Another delimitation was that the study's findings might not be generalizable to light and high-tech manufacturing firms in other provinces or countries.

Significance of the Study

The results of this study could support other decision makers in determining suitable strategies and deploying plans before the disruption caused by AM can displace their firms. Disruptive technologies may not only dislodge existing industries but often also cause social change. Additionally, 3DP enables sustainable manufacturing. Compared to traditionally manufactured goods, AM technology requires less energy (Gebler, Schoot Uiterkamp, & Visser, 2014) when used for producing small series of items (Yoon et al., 2014). Furthermore, as items produced by AM need less long-haul transportation (Chen, 2016), CO_2 emissions are expected to decline (Duchêne et al., 2016). Both aspects could reduce pollution, thereby improving people's quality of life. Furthermore, by utilizing AM production may shift employment back from developing to developed countries, which could attenuate unemployment rates in deprived areas (Gebler et al., 2014; Laplume, Petersen, & Pearce, 2016; Tatham, Loy, & Peretti, 2015). Notwithstanding, Barz, Buer, and Haasis (2016b) pointed out that inbound transportation cost can be lower, but the delivery cost to users may increase.

Some firms in the medical sector using AM technology for medical applications, such as implants, prostheses, rehabilitation devices, and medicines (Ford, 2014; Kietzmann, Pitt, & Berthon, 2015) are thereby reducing the costs of medical treatments and improving people's quality of life. The results of this study could contribute to positive social change through providing solutions managers could utilize to deploy AM technology, thereby increasing local employment opportunities, improving the environment, and enhancing healthcare for the prosperity of local and global citizens.

Review of the Professional and Academic Literature

Pertinent literature indicates that AM technology has the characteristics of a disruptive innovation as its use impacts current business models and supply chains. This literature review included the theory of disruptive innovation and the principles of business models. Furthermore, I provided an in-depth overview of the history, technology, application, social impact, and governance aspects of AM, followed by a discussion on the disruptive aspects of AM for existing firms and the managerial implications.

The primary sources of information were the various search engines that the Walden University Library provided, such as ProQuest, SAGE, Business Source Complete, Science Direct, or Emerald. I used Mendeley Desktop to manage all literature collected. Based on saved searches, some of the search engines automatically presented additional research. Similarly, Mendeley suggested relevant sources based on the content of my library. Furthermore, Google Scholar, linked to Walden's library, proved to be a valuable search engine.

Keywords used for the searches included (either individually or combined):

disruptive innovation, disruptive technology, *business model, supply chain, additive manufacturing, 3D printing, three-dimensional printing,* and *direct digital manufacturing*. Finally, I used citation chaining to identify additional useful sources from the reference lists of articles that I read, thereby quickly expanding my collection of relevant literature. The literature reviewed contains 142 sources, including 136 peer-reviewed articles and government reports (96%), 120 (85%) sources published between 2014 and 2018, and four (3%) seminal books.

The Theory of Disruptive Innovation

The purpose of this multiple case study was to explore strategies that light and high-tech manufacturing firm managers used to adopt AM technology into their business models. The target population included four individual managers, one at each of four different light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. The conceptual framework used in this study was Christensen’s theory of disruptive innovation. Although this theory is popular among managers (Tellis, 2006), it also caused fierce debate among academics (Klenner, Hüsig, & Dowling, 2013). In this subsection, I included the premises of this theory, its critique and countercritique, and the managerial implications.

Christensen (2016) introduced the disruptive technology theory in 1997. Later Christensen used the term *disruptive innovation* theory (Christensen & Raynor, 2003). In this theory, Christensen described a process where initially people are using innovative products or services in uncomplicated situations outside their mainstream application.

Christensen further clarified the difference between sustainable and disruptive technologies and why well-performing companies often fail as the result of such disruptive technologies.

In the failure framework, Christensen (2016) explained three crucial reasons why established companies falter when encountering disruptive innovations. The first factor is the difference between sustainable and disruptive technologies. Where sustaining technologies aim at improving products for existing customers, disruptive technologies produce contemporary goods or services that, initially, provide worse performance than regular items (Christensen, 2016). Christensen argued that disruptive technologies offer more value to mostly new customers because of their different characteristics. Examples of such disruptive technologies are lightweight motorcycles, 3.5" disk drives, hydraulic excavators, mini steel mills, flash memory, inkjet printers, digital photography, or smart phones. Regularly, such disruptive innovations were existing technologies used in a different setting than used before (Christensen, 2016). Companies continuously upgrade their products or services, thereby frequently developing technologies at a higher pace than the actual market needs; this is the second factor (Christensen, 2016). The third element, Christensen posited, is that disruptive products (initially) promise lower margins than existing products, thereby rendering them unattractive and illogical for companies to invest in.

Following the failure framework, Christensen (2016) identified the five laws or principles of disruptive technologies. The first law is that firms depend on current clients and investors for their resources thereby focusing on delivering products or servicing their customers at the highest shareholder return. Consequently, primary stakeholders hold incumbent firms captive (Christensen, 2016). The second law, Christensen argued, is that emerging markets created by disruptive technologies are too small for incumbents to support their revenue growth targets. Third, because such markets are new, no historical data is available to support investment decisions (Christensen, 2016). The fourth principle, Christensen argued, relates to actual business processes, organizational culture and values, which usually inhibit people to work in a distinct way suitable to serve low-profit margin markets. Actual products are repeatedly over-developed and are thereby surpassing customers' needs. In contrast, Christensen discovered that disruptive innovations, although initially underperforming, often catch-up quickly with actual customer needs but at a lower price than existing products and then suddenly replace the existing technology; this is the fifth principle. Notwithstanding, Sood and Tellis (2013) argued that most disruptive technologies do not develop continuously but improve in steps, with many plateaus of abatement. Moreover, some disruptions will take a long time to succeed, but they will still follow the same pathway (Christensen, Raynor, & McDonald, 2015).

Christensen and Raynor (2003) presented a different viewpoint to the theory, arguing innovative technologies typically are not conceived as either sustainable or disruptive. Instead, the way companies use these novel technologies strategically may turn them into a disruptive technology (Christensen & Raynor, 2003). Rather than centering their attention on their products, disruptors put their efforts into establishing a disruptive business model (Christensen et al., 2015). Christensen et al. argued that a typical example of a disruptive innovation is the business model Netflix introduced in a market dominated by Blockbuster who were renting out videotapes and DVDs from shops. Contrary to Blockbuster, Netflix offered an online library and delivered movies by mail to customers who did not care to wait for some time (Christensen et al., 2015). When the Internet enabled Netflix to stream movies instantly, their service also became attractive to Blockbuster's primary customers. Blockbuster's leaders had ignored the disruptive threat Netflix was posing to them; therefore, their company subsequently failed (Christensen et al., 2015).

Startup companies often respond faster to disruptive technologies. Christensen (2016) discovered that startup companies introducing disruptive innovations often have leaner organizations resulting in a substantially lower cost structure than incumbents, which even enhances the attractiveness of these newcomers to the market. By the time the incumbent firms realize the threats posed by the disruptive technology they typically decide to adopt this recent technology, but because these established companies are too late or unable to offer comparable price levels, they quickly lose market share (Christensen, 2016). Through continuous technological enhancements, these disruptive innovations swiftly become attractive to the higher-value marketplaces (Christensen, 2016). Nevertheless, Christensen and Raynor (2003) argued that focusing on sustainable innovations may be the correct strategy for many companies, especially when trying to get ahead of the competition but such plans are inadequate to start a new business. Therefore, managers who want to push incumbent companies out of the market need disruptive, not sustaining, strategies (Christensen & Raynor, 2003).

Despite many cases of strong companies not surviving an innovative disruption attack, examples exist of firms that responded more advantageously. These surviving companies placed the potentially disruptive technology in a separate organization, staffed by people with a passion for the innovation (Christensen, 2016). Leaders who successfully developed a disruptive technology in their organization realized their processes, culture, and cost levels would be unsuitable for further nurturing the innovation. Resulting from their smaller size and overhead, the cost base of these startup companies differed significantly from their main organizations, although they would sometimes use resources from their parents. Next, these separate organizations endeavored to discover or create new markets that would appreciate the possibilities of the disruptive technology (Christensen, 2016). Besides the technological aspects of the disruptive innovation, Christensen argued that disruptive technologies have other elements making them even more disturbing: the weakness of the technology became their advantage and resulting from their simplicity, they are often cheaper, easier to use, and more reliable than established solutions. For example, by creating a market for a disruptive technology, customers who bought the product later appreciated the innovation. Similarly, newcomer companies typically sell their disruptive products at a lower cost and without frills, which make them even more attractive to their buyers (Christensen, 2016).

Not all disruptive innovations have the same effects. Sometimes, the macroeconomic effects of disruptive innovations are opaque (Feder, 2016). Furthermore, Christensen and Raynor (2003) argued that innovations might be sustaining to one firm but disruptive to another. An example is the failure of many newcomers to compete with Dell in selling computers via the Internet. Dell already had the right organizational infrastructure in place to sell equipment via mail orders or telephone (Christensen & Raynor, 2003). Hence, the Internet did not disrupt Dell but sustained it instead (Christensen & Raynor, 2003). Therefore, Christensen and Raynor argued that managers should investigate if their innovations are disruptive to all incumbents, otherwise their disruptive strategy may fail.

Choosing the right business model for a disruptive innovation is essential. Christensen and Raynor (2003) posited that companies utilizing a disruptive low-cost business model to establish themselves and later grow their business could generate substantial profits. Conversely, established high-cost companies attempting to start a low-cost business regularly lose money as they continue to base overheads on their core business model (Christensen & Raynor, 2003). Based on this principle, Christensen and Raynor decided to expand the disruptive innovation matrix with another dimension: new-market disruption. Christensen and Raynor enhanced the theory by arguing disruption could result from different value networks or business models. A value network is an environment from which a company creates a cost structure, ways of working, and relationships with suppliers and partners to fulfill a customer segment's needs profitably.

Additional consumption by new users creates a unique value network (Christensen & Raynor, 2003). Examples are customers who could previously not afford or use the product or service because of its price or other limiting aspects (Christensen & Raynor, 2003). Contrary to low-end disruptions in existing markets, different value networks result in new-market disruptions (Christensen & Raynor, 2003). Nonetheless, Christensen and Raynor argued that many disruptions combine both value networks.

Christensen (2016) continued to hone the theory. In a further refinement Christensen et al. (2015) added the disruptive business model aspects by pointing out that disruptors seek opportunities in low-end footholds whereas incumbent firms focus on their most profitable clients or in the case of new-market footholds, they create a new market (Christensen et al., 2015). Still, Sood and Tellis (2013) argued that attacking an incumbent firm's product core capability has a higher chance of success. Such an attack could either be a lower attack, which happens when a modern technology performs worse than the conventional technology, or an upper attack, in which an innovative technology immediately outperforms the prevailing one (Sood & Tellis, 2013). Contrary to Christensen's theory, innovative technologies targeting a secondary dimension of a product are more expensive than the regular item (Sood & Tellis, 2013). Typically, Sood and Tellis discovered, lower attacks are less worthwhile than upper attacks, but their level of disruptiveness increases when they are cheaper than current products.

Disruptive innovations can affect both engineered products and as mass-produced goods. Where Christensen (2016) mainly focused on mass products, Dedehayir, Nokelainen, and Mäkinen (2014) presented the results of a case study investigating the different aspects of disruptive innovations in complex product systems (CoPS) versus mass-produced goods. Such systems are bespoke, small series, or single item complex and expensive products, often used in capital investments such as oil platforms, production machines, weapon systems, or aircraft engines. CoPS differ from standard products in their value, buyer-seller relationships (mostly business-to-business), high-level of customization, and their longer and more complicated development processes (Dedehayir et al., 2014). Dedehayir et al. believed that disruptive innovations in the CoPS industry have more distinct characteristics than what Christensen included in the theory. Notwithstanding, innovations in CoPS may exist alongside existing technologies for extended periods of time (Dedehayir et al., 2014).

Critique and countercritique. Many scholars criticized Christensen's theory because it lacks a precise definition (Danneels, 2004; Markides, 2006; Reinhardt & Gurtner, 2015). Tellis (2006) argued that the framework lacks sufficient academic rigor, and Weeks (2015) posited that it does not have a unit of analysis. Furthermore, some critics argued that Christensen (2016) founded the theory on post hoc examples only (Markides, 2006; Reinhardt & Gurtner, 2015; Weeks, 2015), and therefore it lacks ex ante application (Danneels, 2004; Klenner et al., 2013; Tellis, 2006).

Indeed, Christensen published mostly in non-peer reviewed publications, such as books and the *Harvard Business Review*. Therefore, King and Baatartogtokh (2015) contended, Christensen (2016) did not provide the opportunity to other scholars to test the theory using quantitative research. This lack of academic rigor resulted in Christensen incorrectly including cases such as Kodak's leaders not reacting adequately to the disruption of digital photography (Weeks, 2015). Weeks indicated that, until the end of the 1990s, Kodak was involved in digital photography, but following Christensen's advice to the firm's leaders, Kodak's managers focused on the lower end of the market only, thereby leaving the high-end digital photography market to others to occupy. When confronted with this ill advice, Christensen argued Kodak's failure resulted from a change in management who decided, against his advice, to disband the independent group focusing on digital photography (Weeks, 2015). Vázquez Sampere, Bienenstock, and Zuckerman (2016) pointed out that more than 40 scientific articles have been published challenging this theory

Christensen (2016) also incorrectly predicted the failure of Apple's iPhone. Christensen believed the iPhone was a sustaining innovation (Weeks, 2015). Instead, Weeks argued that the iPhone did not fit Christensen’s framework as it was neither a sustaining nor a disruptive innovation. Notwithstanding, Weeks argued that this example does not disprove the theory but only shows the importance of accurately defining and delimiting it as just two dimensions cannot explain all innovations. In defense, Christensen et al. (2015) later postulated that Apple introduced the iPhone as a sustaining innovation, but when coupled with the application iTunes and an Internet platform it became a disruptive business model. Hence, the inclusion of the Kodak and iPhone cases gave ground to substantial concerns about the application of the theory and the rigor of Christensen’s research (Weeks, 2015). Weeks believed that the peer review process would have helped Christensen to polish this theory further.

The term *disruption* has a different connotation to many people. Tellis (2006) believed that the biggest problem with the term lies in the use of the word *disruption* as you can only tell a disruption after it has occurred and therefore the theory has limited value. Gans (2016) argued that the term *disruption* has led to confusion, primarily because Christensen (2016) did not accurately define the term. Nagy, Schuessler, and

Dubinsky (2015) argued that Christensen contributed to the confusion by covering two situations in the theory both having a different effect on existing markets: low-end innovations and new market innovation.

Carefully selecting samples for a study is critical. Tellis (2006) questioned Christensen's (2016) sampling methods, as the use of samples to build or to test this theory is not evident. Many disruptive technologies have failed, and for this reason, Christensen has been accused of carefully selecting examples to buttress this theory (Danneels, 2004). Conversely, Danneels argued that business theories are only valuable to managers when they can apply them to portend situations but, unfortunately, Christensen based this concept on post hoc evidence only. Nevertheless, Reinhardt and Gurtner (2015) discovered statistical significance that the theory of disruptive innovation is also useful for ex ante predictions.

Disruptive innovations and disruptive technologies are not synonymous. Markides (2006) argued that the acceptance of Christensen's (2016) disruptive technology theory to explain disruptive innovations is not correct, as they are different events. Despite this critique, Christensen (and Raynor) later expanded the scope of the theory from disruptive *technologies* to disruptive *innovations* (Markides, 2006). Based on a review of academic literature, Markides conversely believed that only two types of disruptive innovation exist: business-model innovations and radical innovations. These types of innovations are fundamentally different, although they may cause similar disruptions as explained in Christensen's theory (Markides, 2006). Nagy et al. (2015) revealed that most scholars who have attempted to describe disruptive innovations mostly focused on market characteristics, low-end innovations, and new markets. Instead, Nagy et al. postulated that disruptive innovation is better understood using Rogers' (2003) diffusion of innovation theory. In this theory, Rogers described the process how customers implement innovations, following a bell-curve pattern starting with innovators, early adopters, early majority, late majority, and laggards. Where Rogers based the theory on innovations initially aiming at the most demanding customers, Christensen's theory of disruptive innovation targets neglected and least demanding customers, a situation which more carefully reflects the rise of AM.

Not all innovations are disruptive. Govindarajan and Kopalle (2006) argued that the disruptiveness of innovations is a latent variable, linked to the abilities of an organization. Therefore, Christensen's (2016) framework is suitable to make ex ante decisions about the level of disruptiveness of innovations and which companies are more appropriate to develop such innovations (Govindarajan & Kopalle, 2006). Govindarajan and Kopalle identified the importance of distinguishing disruptive innovations from radical, but not disruptive, innovations. First, customers valuing low-end disruptions are price sensitive, whereas early adopters of radical innovations care less about the price. Second, radical innovations perform well on their key attributes, but disruptive innovations deliver less. Third, disruptive innovations have new benefits for first adopters. However, radical innovations only provide benefits to the current marketplace. Finally, incumbent firms may be distorted by disruptive innovation, but radical innovations do not pose a threat to existing companies (Govindarajan & Kopalle, 2006).

Markides (2006) believed that business-model innovations and radical innovations emerge differently, leading to different threats to established firms, and requiring other responses. In previous work, Markides used the term *strategic innovation*, but later Markides argued that this was incorrect; *business model innovation* is a more precise term. Business model innovations happen when a company introduces radically different business models in an existing market, as Amazon, EasyJet, Charles Schwab, or Dell did (Markides, 2006). These types of innovations do not introduce different products or services but differentiate their offering, thereby increasing the size of the marketplace through the attraction of new users or by increasing customer spending. Markides further pointed out that companies engaged in business model innovation require different organizations, culture, technologies, and value chains than traditional businesses, a stance echoed by Govindarajan and Kopalle (2006). Firms trying to combine both innovative and traditional business models will encounter many difficulties, and they might even suffer from being stuck in the middle (Markides, 2006).

Despite their differences, the similarities between business-model innovations and Christensen's original disruptive technology theory has erroneously led scholars to believe they are the same (Markides, 2006). Govindarajan and Kopalle (2006) had a different point of view and argued that the amount of disruptiveness of innovations is dependent on how many new customers are interested in the product, as opposed to what the innovation means to mainstream customers. Such innovation can both be high-priced or low-priced. An illustration of such high-priced disruptive innovation is mobile phones (Govindarajan & Kopalle, 2006). Therefore, Govindarajan and Kopalle argued that high-end innovations can still disrupt incumbent firms.

Often technology, instead of customer demand, pushes radical innovations. Markides (2006) argued another type of disruptive innovation occurs when radical, innovative technologies, such as cars, television, personal computers, or mobile phones emerge. Regularly, significant amounts of newcomer companies offer similar but slightly different products (Markides, 2006). After a period of turmoil, the market often collapses when a dominant technology emerges, such as the VHS video recorders. Triumphant companies usually implement the prevalent technology just before it surfaces (Markides, 2006). For this reason, Markides dismissed most of Christensen's (2016) disruptive innovation examples, such as Honda motorcycles, Canon copiers, and Seiko watches. Instead, Markides argued that these firms transformed a niche into a mainstream market.

Ten years after the release of this theory, Christensen and Raynor (2006) wrote a book providing solutions for leaders of companies confronted with disruptive innovations. Unfortunately, Weeks (2015) lamented, Christensen and Raynor still did not reveal further research on the role of the manager but just provided anecdotal evidence that often was mispresented. Christensen and Raynor also argued that company founders are effective in responding to disruptive innovation threats than their succeeding managers, but they did not provide any evidence for this position.

A further concern Weeks (2015) uttered on Christensen’s (2016) work is its lack of a unit of analysis: Christensen applied this theory to companies, industries, leaders, business models, and diffusion of innovations. This ambiguity, together with the disregard for other factors influencing companies' performance, created difficulties applying the theory successfully. Furthermore, Weeks questioned if the theory has an explanation of the agency of business leaders. Likewise, as the theory is two-dimensional, it is too simplistic as it forces each innovation into being either disruptive or sustaining (Weeks, 2015). Nevertheless, Weeks believed that Christensen's theory could be a robust conceptual framework to apply to technological innovations.

One of the fundamental aspects of a disruptive technology is the innovations' possession of a characteristic superior to the existing one. Tellis (2006) argued that this favored feature often is a new facet that the current product is lacking. Therefore, Christensen's (2016) second premise is unfounded (Tellis, 2006). Moreover, Reinhardt and Gurtner (2015) argued that the term *disruptive* is confusing as it describes a potential consequence of innovations, not the real outcome. Hence, Reinhardt and Gurtner inferred, following the manner Christensen described disruptive innovations, these inventions could be vanguards that do not disrupt or could be disruptions not caused by innovations.

The theory of disruptive innovation has prominence with business practitioners but also encountered vast critique from academia. Christensen et al. (2015) feared, despite its success, the theory has become a subject of considerable scrutiny because people often misinterpreted the premises and ignored subsequent refinements of the concept. Consequently, scholars criticized the theory for flaws which the authors already corrected (Christensen et al., 2015). Furthermore, Christensen et al. observed that people are typically using the term *disruption* without having read any of the pertinent literature. Therefore, researchers and consultants incorrectly add this connotation to any innovation shaking up an industry, such as Uber (Sood & Tellis, 2013).

Uber has quickly become a high-value and famous company, transforming the taxi business but is it not disrupting the taxi industry intrinsically (Denning, 2016). This firm increased demand by offering lower-priced services, but they did not create a new market; neither were taxi companies investing in growing services for their customers (Christensen et al., 2015). Contrary to the theory, Uber immediately started to offer improved services compared to existing taxi companies. Therefore, Uber may be disruptive to limousine rental companies instead of the taxi industry (Christensen et al., 2015). Christensen et al. used the Uber example to demonstrate the correct use of their theory is necessary to identify real disruptive innovations when they emerge. Disruptive innovation is an evolving process, not a product or a service and sometimes this process takes many years to displace incumbent firms (Christensen et al., 2015).

Denning (2016) argued that Tesla is another illustration of a company erroneously regarded as a disruptive innovator. Instead, Tesla introduced their electric vehicles in an upscale market with fierce competition (Christensen et al., 2015). Consequently, Christensen et al. expected a strong incumbent to take over Tesla, or the company would likely encounter a fierce battle for market share. Christensen et al. admitted their theory is not intended to be a comprehensive explanation of the effects of innovation on business because more factors influence success. However, Christensen et al. asserted that empirical evidence exists undergirding the theory of disruptive innovation. Christensen et al. gave a more recent illustration of the application of the theory: CISCO’s rise from a small business making inferior routers, not suitable for voice transmission, to the dominant company in the market thereby displacing incumbent firms Lucent and Nortel.

Nevertheless, CISCO is now subject to disruption as new entrants are using inferior technology to chip away market share (Denning, 2016).

Christensen acknowledged the first version of the theory missed the type of disruptions that companies such as Uber, Google, Tesla, and Apple with their iPhones caused (Denning, 2016). Therefore, besides the primary two forms of innovation: sustaining innovations and disruptive innovations, Christensen et al. (2015) argued that the theory needs to be updated to include three ways of innovations: market-creating innovations, sustaining innovations, and efficiency innovations (Denning, 2016). Sustaining innovations were already covered in Christensen’s (2016) original theory and are not disruptive as they are intended for growth. Other types of innovations Christensen also deemed disruptive are efficiency innovations such as those Walmart introduced, displacing many competitors by operating more efficiently (Denning, 2016).

The maturity of the marketplace is tightly linked to its disruptive susceptibility (Klenner et al., 2013). Denning (2016) dismissed this position by pointing out the speed of some technological advancements such as Google Maps, Apple iPhone, Tesla, or Uber disrupting incumbent industries as taxi firms, digital map companies, and mobile phone makers. Bienenstock (Vázquez Sampere et al., 2016) emphasized the significance of Christensen's (2016) theory for business leaders because of its importance when developing strategies and further indicated that, before this theory, uncertainty existed why otherwise well-run companies suddenly failed or stopped growing.

Managerial implications. Managers should apply business theories in the appropriate circumstances. The term *disruption* has an alarming connotation among business leaders (Gans, 2016). However, King and Baatartogtokh (2015) argued that Christensen's (2016) theory of disruptive innovation has value but should be applied sparingly and in the right situation. Christensen (2006) claimed that if companies do not copy a disruptor or fight a disruption, they do so only to survive, and therefore they are not striving for maximum shareholder value. Markides (2006) dismissed Christensen’s position, as it was not empirically substantiated. Instead, Markides posited that companies have many ways to respond to disruptions, including disrupt-the-disruptor, invest in different markets, strengthen their current position, or go global. Markides argued that incumbent companies should focus their resources on doing what they are excellent in, such as growing emerging markets into mature ones. For instance, firms could create feeder companies to colonize new markets that the central group later could take over (Markides, 2006). Instead of the typical retreat strategy, Adner and Snow (2010) argued that old technology could still have a niche to continue. Fountain pens, sailing boats, or piston engines are some examples. Adner and Snow further posited that companies under threat of innovative technology should better proactively retreat and be the first mover in a niche then wait and decline to fight.

Managers can test if the theory is useful for their situation. Christensen and Raynor (2003) argued that to determine an innovation's disruptive potential, business leaders need to perform three tests: first, does a large group of potential consumers exist who currently are constrained to buy this product or service; second, is there a population interested in buying this product or service at a lower price and accepting a lesser performance, and from this, is our firm able to create a profitable business model; and third, is this innovation disruptive to all incumbents? Govindarajan and Kopalle (2006) developed a standard method to measure the level of disruptiveness of an innovation. Govindarajan and Kopalle also discovered that the absence of reliable market size information is the most significant obstacle for incumbent firms to market disruptive innovations. Only incumbent firms having an entrepreneurial, risk-taking, or adhocracy culture are apt enough to develop disruptive innovations (Govindarajan & Kopalle, 2006). Consequently, corporations not having such culture but determined to market a disruptive innovation should establish a separate business unit to do this (Govindarajan & Kopalle, 2006).

Not all company failures are the result of disruptive innovations. Tellis (2006) revealed that the main reason incumbent companies fail attributes to their leaders, not to disruptive technologies. Leading firms ferociously invest in upcoming markets and are even prepared to abandon their existing operations to achieve future profits (Tellis, 2006). Nonetheless, Denning (2016) argued that besides spinning off a disruptive innovation into a separate company, other possibilities exist for incumbent firms to protect themselves against innovative attacks, namely continuous innovation. Apple, Zara, and Amazon are symbols of companies who ingrained innovation in their corporate culture. Furthermore, Tellis argued that technological innovations do not cause disruption of incumbents but emerge from their leaders’ lack of vision combined with a stubbornness to cling on to sunk-cost investments.

When faced with an industry disruption, managers need to know how to respond. Gans (2016) identified three possible reactions to a disruptive innovation threat: beat, join, or outwait the disruptors. Sood and Tellis (2013) warned managers of the danger of not recognizing and adequately responding to new technology by pointing out now-obsolete technologies: typewriters, tape recorders, VCRs, or floppy disks. Such threats might substantially harm or even eliminate companies (Sood & Tellis, 2013).

Sood and Tellis (2013) advised business leaders to instill a culture of alertness in their organization, as inertia towards emerging technologies can be more dangerous than the disruptive technologies itself. Following the perceived limited predictive power of the theory of innovative disruption, King and Baatartogtokh (2015) formulated three alternative strategies managers could deploy when encountering disruptive innovation. First, determine the price of the battle and consider if it is worth the effort; second, make further advantage of existing strengths; and third, join forces with other companies (King & Baatartogtokh, 2015). Furthermore, Denning (2016) warned managers about the disruptive potential of newcomers. Denning emphasized that some incumbent firms are unable to respond adequately because of their inability to imitate the disruptive technology or to respond quickly because the disruptor might be freely giving away their products gratis, as Google did with their maps. However, King and Baatartogtokh argued that no theory is a substitute for sound business thinking. In addition, Feng, Williamson, and Yin (2015) postulated that business leaders need to be cognizant that disruptive innovation results from more factors than technology only; evidence exists disruptive innovations will likely surface from emerging markets.

Besides responding to innovative unsettlement, managers also need to prepare for future disruptions. Klenner et al. (2013) advised managers to generate a pipeline of ideas in times of little disruptive susceptibility. Such ideas, together with constant market surveying, may be used in the period of high disruptive susceptibility before newcomers introduce disruptive innovations. Christensen et al. (2015) also reminded successful companies are often labeled disruptive only because they are fortunate. Notwithstanding, the theory is no roadmap to success. Instead, many cases exist of disruptive innovations that failed (Christensen et al., 2015). Christensen et al. further warned for the ubiquitous belief that companies need to disrupt or be disrupted. Instead, thriving firms should continue to focus on their most profitable clients but simultaneously create stand-alone organizations where they can respond to, or introduce, disruptive innovation (Christensen et al., 2015).

The theory of disruptive innovation is not a lens that managers use to determine how to respond to disruptions. Instead, the concept supports making strategic choices between investing in sustaining or disruptive innovations (Christensen et al., 2015). Gans (2016) warned executives who have identified potential disruption to their companies to act, as having too much self-confidence is an evil advisor in circumstances of disruptive innovations. Osiyevskyy and Dewald (2015) presented a categorization of adaptions of disruptive business model innovation for incumbents. In support of positions taken by Markides (2006) and Christensen (2016), Osiyevskyy and Dewald argued that disruptive technologies are just precursors of disruptive business model innovations. Moreover, Holm, Günzel, and Ulhøi (2013) posited that technological discontinuities had been the basis of many business model innovations. In such circumstances, managers of established firms sometimes encounter difficulties to decide whether to explore such new models or to exploit proven models. Business models are the foundation of a company's competitive advantage and are separate from market positioning or market strategies (Osiyevskyy & Dewald, 2015). However, Osiyevskyy and Dewald considered that companies can still lucratively apply innovations in different business models.

Business Models

The principles of business models have a become a favorite research topic for academics. Although many studies on business models exist, a standard definition is still lacking (Christensen, Bartman, & Van Bever, 2016). Holm et al. (2013) defined a business model as a concept explaining which parts of a business are responsible for generating a delimited part of the value created and captured. The pioneers of the business model concept, Zott and Amit (2013), construed a business model as a system of mutually dependent activities performed by a company and its partners and process linking them activities together. Moreover, Zott and Amit argued that business models deliver value through efficiency, innovation, lock-ins, and reciprocation. Business models focus on how firms conduct their business from an integrating perspective by creating value for all partners involved (Zott & Amit, 2013).

Although academia and practitioners apply the concept of business models, some scholars refute it. Arend (2013) sullied Zott and Amit's concept of business models, by equating it to a *Skeuomorph*, an obsolete attribute of a new product added to comfort users who reminisce about the older product. Despite this criticism, the concept of business models is useful when determining business strategies to disrupt a market or to withstand a disruption (Markides & Sosa, 2013). Still, Amit and Zott (2015) recognized that this concept still requires further refinement through future research.

Implementing an advanced business model can be a daunting task for incumbent firm managers. In response to calls for more research, Berends, Smits, Reymen, and Podoynitsyna (2016) discovered that companies innovate their business models according to a drifting or a leaping pattern. The drifting pattern mostly originates from an operating business model, uses experiential learning, followed by a cognitive search in later stages (Berends et al., 2016). Conversely, the leaping pattern is a cognitive model going into operation late, followed by a phase of experimental learning (Berends et al., 2016). As differences exist in how companies plan to innovate their business models and how they operate it, Berends et al. argued that business models are a combination of mental models and organizational implementation. Therefore, innovating business models does not follow a simple two-step process of design and implementation, but instead, such innovations are processes of continuous development with feedback loops, following either a drifting or a leaping model (Berends et al., 2016). Developing new business models based on disruptive technology, such as AM, brings extra complexity as the technology has morphed from RP to direct digital manufacturing (DDM), developing into consumers making their own products (Rayna & Striukova, 2016).

Additive Manufacturing

AM is a manufacturing technology building up products layer by layer. Initially, this technique was called RP, and today the common name is 3D printing (Gibson et al., 2015). In this subsection, I will discuss the history and technology of AM, the applications, governance, and social impact. Furthermore, I will consider the effects on business models and supply chains.

History. AM is not recent technology. The origin of AM goes back to the 1950s and 60s (Gibson et al., 2015). In the early 1980s, various French, Japanese and American inventors filed for patents, but the common belief is that Hull invented stereolithography in 1983 (Gibson et al., 2015; Hull, 2015). Nevertheless, Gao et al. (2015) discovered that Householder obtained the first patent related to 3DP in 1981. More patents received issuance later, but Scott Crump and a team from MIT who patented the 3DP method received the most noteworthy ones (Gibson et al., 2015).

When employed by a corporation, Hull (2015) invented the ultraviolet microscope, but the company's president was not interested in pursuing this invention further as no market for such products existed; a similar experience to Christensen's findings. Later, Hull conceived the idea of stereolithography to produce prototypes quicker, but Hull was unable to convince the firm's leadership of the potential of this idea either, but Hull's manager allowed him to work on this idea, outside working hours, in the company's laboratory. In 1986, after Hull obtained a patent for this invention and wanted to develop the concept into a product further, Hull started a company: 3D Systems (Hull, 2015). Computer-aided design (CAD) tools were essential to the success of 3DP, and Hull also worked closely with software companies to enhance CAD software to augment 3DP. Hull (2015) noticed that in the United States, some industries like automotive and aviation were immediately interested in applying these innovative technologies. Conversely, in Japan, only a few corporations showed excitement for AM, which resulted in the demise of Japanese 3DP firms (Gibson et al., 2015).

Arising out of the many patents and their owners' fierce protection, companies used the technology mostly for rapidly creating prototypes. Upon the expiration of some essential patents in 2004 and 2009, more competitors entered the market resulting in substantial growth of AM equipment sold (Gibson et al., 2015). Among the first companies to use AM equipment were General Motors, Eastman Kodak, Baxter Healthcare, Pratt & Whitney, BF Goodrich, and Texas Instruments defense division (Gibson et al., 2015). These firms represent the automotive, consumer products, aerospace, healthcare, and defense industries, thereby signifying the most influential industrial sectors. After the car industry embraced this technology to make prototypes, the first service companies began offering 3D printed products and the technology became more mainstream (Hull, 2015). Park, Kim, Lee, Jang, and Jun (2016) discovered that the first eight patents related to 3DP received issuance in 1980. The eighties and nineties showed a slight annual increase in patents filed, but since the 2000s the annual amount of patent filings grew considerably, peaking at 164 in 2011.

The acceptance of 3DP is still growing. Hull (2015) gave examples of its utilization in the dental and hearing implants, jewelry, power, aviation and space, and consumer product industries. Although the primary application of AM was with the do-it-yourself and maker movement platforms (Gao et al., 2015), Mashhadi, Esmaeilian, and Behdad (2015) argued that AM had undergone a dramatic transformation, which still has not ended. Gao et al. (2015) expected the scale and quality of the AM technology would soon improve sufficiently to enter mainstream markets. For example, Gao et al. indicated that General Electric is already investing substantially in AM factories to reduce their dependency on suppliers, extend the lifetime of their aircraft engines, and produce fuel nozzles for their LEAP aircraft engines (Gibson, 2017). Furthermore, Gao et al. believed that AM could enable small firms and end-users to be more independent and innovative.

Technology. Computer technology has substantially enhanced the efficiency of manufacturing. Examples are computer-numeric controlled (CNC) machines, CAD, computer-aided engineering, computer-aided manufacturing, and computer-integrated manufacturing (Chen et al., 2015). Whereas traditional manufacturing requires careful studying an article's geometry to understand how to manufacture and assemble it, AM users only need to know how to operate the equipment and what materials to use (Gibson et al., 2015). The AM process consists of eight steps. First, an electronic data file needs to be available, either created with CAD or scanning equipment. Second, the data file is converted into an electronic file in which the model is sliced. Third, the file is transferred to the printing equipment. Fourth, the operator needs to set up the AM equipment. Fifth, the AM machine makes the product. Sixth, the operator removes the parts from the machine. Seventh, cleaning. Finally, the item may require some further treatment, such as surface polishing (Gibson et al., 2015). Gibson et al. posited that when comparing the speed of the AM process with traditional CNC manufacturing the AM process is much faster, in case the CNC process requires multiple steps, setups, or different machines.

Recently, ASTM developed an alternative electronic format for 3DP files as a replacement for the commonly used files. This new file format is backward compatible with the previous file format and resolved some known issues the old file had (Brown, Lubell, & Lipman, 2013). ASTM’s F42 committee officially named this technology AM because it is it different from traditional, subtractive manufacturing (Gao et al., 2015). Kelly and Jennings (2014) distinguished between 3DP and AM by labeling 3DP a process to create parts directly from CAD files and AM as a comprehensive process, like conventional production. Bogers et al. (2016) differentiated AM from RP, whereby they considered RP a technology used to create prototypes later used in mass-production, and AM as a production process for end products. Conversely, Holmström, Holweg, Khajavi, and Partanen (2016) used the term DDM because the technology is suitable to produce parts directly from digital designs**.**

Using AM has benefits and downsides. Bogers et al. (2016) assessed the six most used AM technologies on their characteristics, pros, and cons. The leading techniques are fused filament fabrication, selective laser sintering, stereolithography apparatus, direct light processing, polyjet matrix, and Inkjet ZCorporation technology. For each of these technologies, Bogers et al. considered the following eight aspects: mechanical properties, chemical properties, visual finish, cost, time, volume, multicolor, and decoration. From this assessment, Bogers et al. observed that fused filament fabrication had the highest overall score. Other technologies such as polyjet matrix, suitable to print biocompatible materials, and selective laser sintering that enables combining colors, may be appropriate in future but are unsuitable for consumer goods manufacturing (Bogers et al., 2016).

AM has not been fully developed. Gibson (2017) emphasized that AM comprises many different technologies at different stages of maturity. Holmström et al., (2016) described a recent development called continuous liquid interface production, which they considered has substantial growth potential as this technology could create products 25 to

100 times faster than current DDM equipment and, in future, even 3D printed holograms. Another recent development is *rapid freeze prototyping* by which AM machines create shapes using water in a room below zero; companies can use this technology as an environmentally friendly alternative for investment casting molds (Guo & Leu, 2013). Gao et al. (2015) listed recent enhancements of AM technology: equipment capable of printing assembled units with microscopic gaps between the parts so they can move, or machines that can embed foreign objects during printing, such as sensors, motors, or studs. Another promising development is the possibility to include functionally gradient materials in AM (Gao et al., 2015; Gibson, 2017). Using such materials, engineers may develop products capable to change shape when in contact with a particular temperature, pressure, or current, giving them design freedom (Gao et al., 2015). This technology is also called *4D printing* (Duchêne et al., 2016). AM, Lehmhus et al. (2015) argued, is the only suitable manufacturing process allowing to embed sensors. Notwithstanding, Oropallo and Piegl (2016) argued that the technology has been over-hyped, and like any other technology, it has certain flaws and challenges.

Application. Building items layer by layer brings design freedom and generates less waste. As a result, products made by AM can be lighter (R. Huang et al., 2015; Lindemann, Reiher, Jahnke, & Koch, 2015), or stronger than products made by traditional manufacturing processes (Duchêne et al., 2016; Liu, Huang, Mokasdar, Zhou, & Hou, 2014). Moreover, Thiesse et al. (2015) mentioned the adoption of AM enables creating products companies cannot create with any other manufacturing process. The total amount of energy required using AM is lower compared to conventional production methods (Gebler et al., 2014; Huang et al., 2015) and it requires less raw materials to produce items (Burkhart & Aurich, 2015; Lindemann et al., 2015). The freedom of design enables manufacturing of complex (Mashhadi et al., 2015; Slotwinski, 2014), customized (Waller & Fawcett, 2014; Weller, Kleer, & Piller, 2015), or even personalized products (Bogers et al., 2016; Gress & Kalafsky, 2015). Those items could be made in small series (Ford, 2014; Sasson & Johnson, 2016), up to single objects (Brean, 2013; Thomas & Gilbert, 2014).

Before the rise of AM technology, only artisans could produce small series or unique products. Producers could only achieve customization and individualization at excessive cost (Brean, 2013; Chen et al., 2015). Nevertheless, reliability and controllability were hard to achieve (Sandström, 2016). The hearing aid and medical prosthetics industries were early adopters of AM (Beyer, 2014) as they require elevated levels of customization (Holmström et al., 2016). In 1989, Siemens conducted a feasibility study of deploying AM for hearing aids; in 2016, almost the entire global hearing aid industry moved from manual production to 3DP technology (Sandström, 2016). Moreover, Dumitrescu and Tănase (2016) discovered that American hearing aid companies all moved to production with AM within less than 2 years.

Resulting from these unique manufacturing aspects in combination with the possibility to optimize product design, some companies have achieved remarkable results in improving some of the parts used in their products. To illustrate: engineers at Airbus used AM to create parts that were 67% lighter, and General Electric redesigned fuel nozzles as one unit, originally consisting of 18 parts (Knofius, Van der Heijden, & Zijm, 2016), reducing their weight by 84% (Camisa, Verma, Marler, & Madlinger, 2014). Other examples are Lockheed Martin's joint strike fighter brackets and Airbus' aircraft components, using 90% less energy and weighing 30-55% less (Camisa et al., 2014).

Assertive customers are demanding faster delivery and more personalized items. Lindemann et al. (2015) postulated that the modern manufacturing industry is a highly competitive, global sourcing environment encountering increased customer demands for innovative and customized or individualized products. Furthermore, because the lifetime of goods is reducing, a faster time-to-market is required; AM can support these needs (Khorram Niaki & Nonino, 2017b; Lindemann et al., 2015). Despite, Lindemann et al. argued, resulting from the more complicated way to design 3D printed items, the product development process requires extra time. Salonitis and Al Zarban (2015) concurred by pointing out that current design methods are based on subtractive manufacturing processes and are therefore limiting developers' creativeness.

The development and implementation of AM goes faster than expected. Weller et al. (2015) referred to reports from research firm Gartner, that showed that in 2012 AM peaked at maximum expectations. However, AM technology still is not mature enough to meet such expectations because in 2014 Gartner considered AM to become a standard manufacturing process between 2016 and 2020 (Weller et al., 2015).

Today, the most commonly used raw materials in AM are plastics, metals, alloys, wood, ceramics, and chocolate (Rayna & Striukova, 2016). Weller et al. discovered that some cases of propitious AM adoption: Nike has used AM to produce customizable soccer shoes, Runner Service Lab provides tailor-made running shoes. Ford (2014) mentioned the successful tests conducted by Cornell University to practice AM with living body cells to produce a human ear, which could revolutionize medical practice. Brown et al. (2013) stated that doctors are printing skeleton replacement parts and mentioned that the medical industry is already experimenting with 3D printed organs. Other illustrations of fruitful AM application are a full aircraft wing and rocket engine injectors for NASA, which was done in 4 months and only cost 30% compared with the traditional method (Ford, 2014).

The construction and building industries are other sectors affected by AM. The University of California developed the Contour Crafting technology whereby buildings can be 3D printed, using cement (Camisa et al., 2014). Brown et al. (2013) discovered that the construction sector has started utilizing AM to build small structures. Chinese company Winsun demonstrated the ability to 3D print a five-floor concrete apartment (Steenhuis & Pretorius, 2017), and Kothman and Faber (2016) discovered evidence 3DP with concrete allows designing and constructing unique buildings at the same cost of conventional structures. Unfortunately, engineers are currently underutilizing the design freedom AM enables (Gao et al., 2015; Simpson, Williams, & Hripko, 2017). The basis of regular design methods are subtractive manufacturing processes, thereby limiting developers' creativity (Salonitis & Al Zarban, 2015). Therefore, an upcoming engineering field, called design for AM, should alleviate this issue (Salonitis & Al Zarban, 2015).

A remarkable area for the application of AM technology is the food production industry. NASA is experimenting with 3D printers that produce pizzas in space (Laplume et al., 2016) and recently, a restaurant opened in the Netherlands serving 3D printed food. In the United Kingdom, a company called ChocEdge has started to sell 3D printed chocolate products (Jia, Wang, Mustafee, & Hao, 2016; Li et al., 2014). Gibson (2017) expected 3D food printing to be the first substantial consumer use of this technology. With these various areas of application, new governance in the areas of legislation, quality assurance, warranty, and health, safety, and environment will be required.

Governance. The European Commission (2014) highlighted that specific issues related to AM had not been adequately addressed. The Commission mentioned intellectual property (IP) protection, product liabilities protecting consumers, lack of standards, product testing and certification, taxation, duties, and environmental issues. Such problems inhibit the use of AM technology

Laws and standards. Our worldviews of how to make things formed the basis of our current codes and legislation. The use of AM revealed various shortcomings that need addressing (Santoso & Wicker, 2014). In recent years, more raw materials became available, and AM equipment became much cheaper, which has boosted the diffusion of this technology, but standards and regulations have not developed at the same pace (Gao et al., 2015; Mellor, Hao, & Zhang, 2014). Zanetti, Cavalieri, and Pezzotta (2016) pointed at the blurred liabilities between third party service providers and design owners. Additionally, Garrett (2014) pointed at the security and military consequences of AM, such as 3D printed guns or improvised explosive devices, and argued that governments need to develop and adjust policies and laws to address these disruptive aspects AM.

The lack of standards and unclear product liability constrains the proliferation of

AM. Examples are highly regulated industries, such as aerospace (Slotwinski, 2014). In addition, Brean (2013) argued that existing patent law needs updating to protect copyright holders but also will enable further innovation. On another area, Neely (2016) posited that suppliers using 3DP to manufacture products will still have to comply with product safety laws, but the applicable legislation does not protect consumers making products themselves, using AM. Therefore, Neely called for professional bodies like the Institute of Electrical and Electronics Engineers or the American Society of Mechanical Engineers to develop standards for designing products made by 3DP. Similarly, Kietzmann et al. (2015) said that these ethical and IP aspects are all relevant matters policy- and lawmakers should consider.

Intellectual property. The combination of IP and AM is a concern for many scholars. For example, some aspects of IP are hindering the growth of 3DP (Brean, 2013; Camisa et al., 2014) but other factors are threatening the rights of patent holders (Bogers et al., 2016; Kurfess & Cass, 2014). IP laws aim at protecting creations of the mind such as designs, art, literature, or images (Santoso & Wicker, 2014). Resulting from companies like 3DP service provider Shapeways, traditional business models have changed (Brean, 2013). Accordingly, Brean argued that existing patentees should assess their level of protection against infringement. Santoso and Wicker (2014) expected that most IP cases would be pursued based on copyrights instead of patents, although the situation appears blurred when people take unique designs, modify them and share them as their own, so-called derivative models. Contrary to copyrights, patents do not allow for fair use replication of protected objects (Santoso & Wicker, 2014). For instance, people replicating spare parts will likely be breaking patent laws, even when they are just replicating the design. Consequently, online platforms, such as Shapeways, could be held liable for violating patent or copyright laws and some individuals have already received cease orders for replicating board game figures (Santoso & Wicker, 2014).

3DP requires a data file, either the original CAD file or data generated by a 3D scanner. Therefore, using a company's CAD files illegally would be a breach of copyright (Neely, 2016). Brean (2013) argued that printing a protected item is a patent infringement, but when consumers do this, law enforcement is complicated. As a result, patentees might turn to sellers of CAD files for compensation, although these parties are not violating the patent law because they are not selling protected items. Patents do not cover CAD files or blueprints, as they are not used to produce the protected item nor are part of it (Brean, 2013). Brean dismissed Santoso and Wickers' arguments by pointing out copyrights neither protect against the creation of CAD files or 3D printed copies of protected items unless the item has a unique pictorial, graphical, or sculptural aspect. Considering current IP laws and the way people use them are not adequately covering the legal complexities emerged by AM, Santoso and Wicker argued that all stakeholders in 3DP should collaborate to conclude protecting interests of both creators and AM users. Furthermore, Santoso and Wicker emphasized that 3DP users should take the initiative as new laws, policies, and standards will have a significant impact on what 3DP users can do. Finally, Lindemann et al. (2015) posited that products made by AM require protection against illegal copying by carefully designing items, enabling patent owners to reduce the risk of product piracy.

Quality assurance and inspection. Some governmental organizations have become aware of the challenges that AM poses to existing legal frameworks. For example, the European Commission and the American National Institute of Standards and Technology are concerned about the lack of standards for AM and the consequences for the quality assurance of parts made with AM (European Commission, 2014; Thomas & Gilbert, 2014). Using AM also has certain disadvantages: raw materials used in AM equipment does not always match the characteristics of raw materials used in traditional manufacturing, the process is slow, additional surface finishing may be required, and the absence of quality control standards complicated part inspection (Weller et al., 2015). Particularly in the aviation industry, quality assurance is a concern for parts made with AM (Wagner & Walton, 2016). Lack of standardization is a barrier to further diffusion and implementation of AM (Monzón, Ortega, Martínez, & Ortega, 2014). Moreover, Kietzmann et al. (2015) pondered when users make products themselves on 3D printers, based on designs they have acquired elsewhere, where does product quality liability rest?

The characteristics of raw materials utilized in the AM process influences the quality of the product. Dawes, Bowerman, and Templeton (2015) argued that the quality of the powder has a substantial effect on the quality of AM final products. The most prominent challenge for AM technology currently is the quality assurance of raw materials (Dawes et al., 2015), a situation caused by the origins of AM technology in RP (Dawes et al., 2015). Feedstock for 3D printers are powders that AM equipment vendors and powder-producing companies sell (Dawes et al., 2015). AM equipment suppliers sell validated AM powders that they guarantee to be suitable for use in their equipment, but this comes at a premium cost and has less traceability (Dawes et al., 2015). Additionally, as raw materials represent a substantial cost of an item produced with AM, recycling of powder is essential (Dawes et al., 2015). Dawes et al. also argued that limited research exists on the effect on quality of products using recycled feedstock. The European Commission (2014) indicated issues exist inhibiting the acceptance of AM technology. Such matters include IP protection, lack of standards, product testing and certification, taxation, duties, environmental issues, and product liabilities protecting consumers (European Commission, 2014; Fornea & van Laere, 2015).

Product warranty, liability, health, and safety. AM technology affects current legislation. When lawmakers developed their rules, they did not consider the consequences of copying physical objects (Mohr & Khan, 2015). Furthermore, the liability for products defects are unclear (Bogers et al., 2016; Chen et al., 2015; Ford, 2014). Consumer's contributions to designs or even printing their products could result in problems with warranty and product liability (Neely, 2016). An example of such an issue would be when consumers do not follow the product manufacturer's speciation or parameters or use different production equipment (Bogers et al., 2016; Holmström et al., 2016). Additionally, AM technology enables individuals or small groups to produce small and heavy weapons, a privilege only governments and specific industries previously had (Mattox, 2013). Still, Neely (2016) indicated that the concerns that arose when someone 3D printed a gun is more of a security concern than a product safety issue. Consequently, the authorities will encounter difficulties avoiding the proliferation of weapons, which will affect people's and state's security (Mattox, 2013). Moreover, weapons made of metal can now be created in plastic, thereby complicating their detection in public places (Mattox, 2013).

How a novel technology affects workers' health and safety is imperative. Indications of improved operators' health exist but whether materials used in the AM process are harmful to employee's health has not been thoroughly investigated (Ford & Despeisse, 2016; Kohtala & Hyysalo, 2015; Short, Sirinterlikci, Badger, & Artieri, 2015). Additionally, Slotwinski (2014) revealed that some of the health and safety risks associated with the use of AM, especially powders used as raw materials: explosion risk, the risk of people breathing in grit, or damages to workers' skin or eyes (Khorram Niaki & Nonino, 2017b). Short et al. (2015) subscribed to these concerns but discovered that the Occupational Safety and Health Administration is not investigating nor considers the potential hazards of using AM in production environments.

The Disruptive Characteristics of Additive Manufacturing

Politicians have noticed the disruptiveness of AM. In the State of the Union speech, President Obama (2013) stated 3DP has the "potential to change the way we make almost anything" (5:30). AM has not yet reached the same level of adoption as traditional production methods, but indications exist 3DP has ignited the third industrial revolution (Andrews, 2015). Yao and Lin (2016) confirmed these thoughts. Scholars such as Amshoff et al. (2015), Bogers et al. (2016), Gibson et al. (2015), and Hahn, Jensen, and Tanev (2014) considered AM to be a disruptive innovation. D'Aveni (2015) has regularly published on this topic and expected AM to upturn businesses in the short term. Still, Holmström et al. (2016) criticized D'Aveni, who, they argued, has over-promoted

DDM technology based on its theoretical potential but these arguments were lacking economic perspective and reality checks. Indeed, some scholars argue because the technology is still developing, the disruptive aspects are still to fully emerge (Brennan et al., 2015; Kietzmann et al., 2015). Despeisse et al. (2017) argued that 3DP is shifting existing manufacturing paradigms.

Peer-to-peer technology disrupted the music industry. Appleyard (2015) argued that AM's disruptive characteristics arise more from consumers violating IP, similar to P2P. Waller and Fawcett (2013) postulated that AM will make conventional business models and supply chains antique and emphasized the disruptive aspects of AM: no more economies of scale, consistent quality, less capital investment required to start producing a broad range of different goods, or the maker movement where consumers become product designers and producers. Petrick and Simpson (2013) called such people *prosumers.* To understand why AM, despite the higher cost, is considered by many to be the next manufacturing revolution, Baumers, Dickens, Tuck, and Hague (2016) pointed at history: AM originated from the need to create prototypes faster, a requirement not focused on cost but speed. From there, 3DP had the potential to be utilized for making serial products. Furthermore, when using AM beyond prototyping, users discovered the possibility to create products designed differently (Baumers et al., 2016). Thus, Baumers et al. argued that AM followed the standard technology push principles, instead of a market pull. Consequently, when moving from RP to the traditional manufacturing arena, cost-effectiveness became an essential factor (Baumers et al., 2016) but supply chain considerations also affect AM adoption (Oettmeier & Hofmann, 2016a).

Business models. The success of disruptive innovations is interlinked with the business models in which managers apply them. Amshoff et al. (2015) posited that disruptive technologies, such as AM, both pose a threat and offer opportunities to incumbent companies as they affect established value chains and initiate new business models. Rayna and Striukova (2016) discovered that few studies exist on the impact of 3DP technologies on business model innovation exists. For this reason, Rayna and Striukova conducted research and found that RP and rapid tooling had minimal effect on current business models but, resulting from the reduction in the cost of the equipment, direct manufacturing, and home fabrication may be highly disruptive. Laplume et al. (2016) argued that although 3DP is unsuitable for the conversion of raw materials, it has powerful application in markets where customers demand customization or fast delivery, and when products have intricate designs.

AM is a disruptive technology having substantial consequences for many industries and firms. Bogers et al. (2016) expected AM to revolutionize the production processes of the consumer goods industry. Therefore, 3DP poses a significant problem to, but also opportunities for, companies' existing and contemporary business models (Bogers et al., 2016). However, Steenhuis and Pretorius (2016) argued that when consumers use AM on a larger scale, this will affect actual business models, but not in the way Christensen defined disruptive innovations. Ortt (2017) confirmed AM is a disruptive innovation that currently only affects niche markets. Amshoff et al. (2015) argued that extant business models are often not suitable for disruptive technologies as the market for their products is just opening. Following, Amshoff et al. referred to Kodak that, in the light of being a leader in the disruptive digital photography, maintained their current razor-and-blade business model and perished.

Supply chains. Local production of goods will affect existing supply chains. Therefore, Mohr and Khan (2015) posited that 3DP technology is one of the most disruptive innovations impacting global supply chains. More specifically, Holmström and Partanen (2014) applied Brian Arthur's theory of combinatorial technological evolution to examine and demonstrate possible supply chain transformations. Holmström and Partanen concluded AM has the potential to transform the supply chains of complex, high-value equipment, mainly in the areas of after-sales service. Moving manufacturing closer to the end user, reducing inventory (cost), and demand consolidation all are opportunities for supply chain transformation (Khorram Niaki & Nonino, 2017a). Holmström and Partanen believed that logistics service providers would be the catalyst for this transformation, but they emphasized that product re-engineering will be required to establish the critical mass needed for AM to utilize the potential for change entirely. Similarly, Sasson and Johnson (2016) argued that DDM is likely to become a mainstream production process affecting supply chains and market structures, production, and sustainability. Therefore, AM could exist side-by-side with and in addition to traditional manufacturing (Rogers, Baricz, & Pawar, 2016; Sasson & Johnson, 2016; Waller & Fawcett, 2013). From a quantitative study, Barz et al. (2016b) concluded AM can affect existing supply networks but only when the switching cost from existing factories to new ones are low enough, and sufficient available production sites are available. However, Durach, Kurpjuweit, and Wagner (2017) concluded prosumers, lower inventory requirements, and mass customization would have insignificant effects on existing supply chains.

Considering its efficient process, quick delivery time, and optimal resource usage, AM can enhance supply models. Mashhadi et al. (2015) argued that leagile supply chains are possible and identified four possible business models. The first model is Local-for-Local, where locally based shared equipment is used to produce for the local market and the second model is economies of scope, where the same machines are used to manufacture different products. Mashhadi et al. further identified virtual supply chains in which firms provide their designs to local manufacturers or users and cloud manufacturing, where companies that own 3DP equipment manufacture products based on other people's designs.

Nyman and Sarlin (2014) compared 10 principle possibilities of using 3DP with the operational characteristics of lean, agile, and leagile supply chain management strategies. Next, Nyman and Sarlin identified four main opportunities for 3DP: green operations; cost-efficient flexibility of decoupling points; small economies of scale; and redefinition of how, where and who. Similarly, Christopher and Ryals (2014) argued because of limited resources and wastage, big data supply, and modern technologies supply chains need to evolve into demand chains. These demand-chains will be buyer dominant, and technologies such as AM will accelerate this process (Christopher & Ryals, 2014).

AM technology minimizes the number of nodes in a supply network. This reduced complexity decreases the risk of supply chain disruption (Thomas & Gilbert, 2014). Additionally, deploying AM enables localized production in small factories, which further reduces the risk of supply disruption (Thomas & Gilbert, 2014). Besides these benefits, Mohr and Khan (2015) argued that 3DP has substantial capacity to disrupt current supply chains and call for supply chain managers to be aware and be prepared.

Social implications. Using AM has a broad impact on society, but the effects are not well understood (Ford, Mortara, & Minshall, 2016). Gebler et al. (2014) conducted a qualitative study towards the three sustainability factors: economy, environment, and society and concluded that AM technology has the potential to sustainably lower energy consumption and CO2 emissions. The European Commission (2014) argued that AM could disconcert existing value chains, but it could also substantially support the European economy because of the potential to create additional employment positions. AM technology has the potential to positively affect the European economy by bringing back high-tech manufacturing jobs to Europe (European Commission, 2014) and America (Schniederjans, 2017).

Notwithstanding this anticipated shift of labor, Garrett (2014) recognized opportunities for governments in developing countries to support local production, utilizing 3DP. Besides the safety, security, and military challenges AM brings, Garrett expected 3DP to cause substantial social and geopolitical impact. Similarly, AM has the potential to positively affect society by enabling lighter and therefore higher fuel-efficient transportation, enhanced medical treatments (Brown et al., 2013; Petrick & Simpson, 2013). Chiu and Lin (2016) mentioned the sustainability benefits of AM by referring to the US Department of Energy that estimated this technology could save energy up to 50%

and material up to 90%.

Using AM may also improve emergency responses. Tatham et al. (2015) argued that 3DP technology has a positive social impact as it mitigates logistical challenges during rescue activities, such as out-of-stock, long lead times, or hold-ups during customs clearance. Despite this potential for positive social change, governments and academics need to understand and acknowledge this potential and remove roadblocks for it to come to fruition (Gebler et al., 2014)

Resource usage. Considering the freedom of design and the reduced amount of waste during fabrication, products created with AM require less raw materials. As a matter of caution, Faludi, Bayley, Bhogal, and Iribarne (2015) argued that earlier studies incorrectly averted that AM has environmental benefits over traditional manufacturing without providing support or by examining single aspects of environmental impact only. Faludi et al. conducted tests using conventional CNC equipment and two AM machines: a fused deposition modeling machine and a polyjet. From these tests, Faludi et al. considered preceding claims that 3DP is more environmentally friendly than traditional manufacturing depends on the equipment utilization rate, which has a substantial effect on energy usage. Nevertheless, at maximum use, material usage and waste creation of AM equipment compared to CNC machines is substantially lower (Faludi et al., 2015).

Pollution. Resulting from simpler and shorter supply chains goods produced by AM require less transportation. Gebler et al. (2014) argued that the industrial sector needs substantial changes to become more sustainable as this area uses 22% of the world’s total final energy consumption and produces 20% of global CO2 emissions. Huang et al.

(2015) researched the potential energy savings and reduction in greenhouse gasses for aircraft parts manufactured by AM. Airplanes consume a substantial amount of fuel and consequently are a significant contributor to air pollution. Reducing the weight of planes by using lighter components made with 3DP will be a significant contributor to the reduction of greenhouse gas emissions (Wagner & Walton, 2016). Huang et al. discovered that up to 6.4% fuel consumption reduction is achievable when making components with AM. Moreover, Huang et al. estimated 33%-50% energy reduction during manufacturing is possible with 3DP compared to conventional methods. Furthermore, as AM enables producing goods closer to where their area of use, shorter and more straightforward supply chains will emerge requiring less amount of transportation emerge (Barz, Buer, & Haasis, 2016a) thereby reducing CO_2 emissions (Garrett, 2014). Despeisse et al. (2017) posited that 3DP could support circular economies. Nevertheless, Brennan et al. (2015) warned for over-optimism as increased amounts of consumerism could lead to increased waste production. Hence, the European Commission (2014) indicated, although some consider AM an environmentally friendly manufacturing technology, it still produces some waste that companies need to manage.

Employment. Moving production activities back to Western countries will positively affect local employment. Brennan et al. (2015) investigated the increase or decrease of offshoring of manufacturing related to contemporary trends, such as lean or AM. Brennan et al. referred to a 2013 study by the Boston Consulting Group who discovered that 21% of United States manufacturers were relocating or planning to move manufacturing back to the US; however, research in Germany in 2012 showed lower numbers. Therefore, Brennan et al. argued that the trend of reshoring is visible but not (yet) significant, but they considered AM has the characteristics to accelerate this process.

Labor cost in developed nations are higher than in developing countries, but this does not necessarily result in cost increases for products made with AM. Achillas, Aidonis, Iakovou, Thymianidis, and Tzetzis (2015) argued that AM is suitable for producing low-volume products, or items requiring multiple molds which is the source of longer lead times. Because AM does not require intensive supervision, labor cost becomes less important. Resultantly, Achillas et al. argued that companies would be able to manufacture closer to their customers in a customized way, so-called *glocalization*, which provides an additional competitive advantage; a benefit of AM often overlooked.

The effect of 3DP on global value chains mainly lies in the relocation of labor from centralized manufacturing locations, such as China, closer to consumers (Garrett, 2014; Laplume et al., 2016). Moreover, Lehmhus et al. (2015) posited that AM will disrupt global supply chains and will move manufacturing back to higher-wage regions that have lost their making industry. Van der Zee, Rehfeld, and Hamza (2015) argued that reshoring would only occur on a visible scale after firms employ 3DP for mass production. Consequently, Kianian, Tavassoli, Larsson, and Diegel (2016) demonstrated using AM could create job opportunities for low-volume, complex design products in Western countries but this would require substantial redesign of such products. Sandström (2016) ascertained when the entire hearing aid industry adopted AM, this did not result in disruption because the whole sector was involved, which only consisted of six companies. Notwithstanding, 3DP destroyed existing competencies by removing manual work artisans perform, it did not result in competence-destruction as firms only used AM at the component level, not the end product level (Sandström, 2016).

Brennan et al. (2015) pointed at the lack of skilled labor in areas where traditional manufacturing has disappeared, thereby creating barriers for reshoring production. Furthermore, Simpson et al. (2017) highlighted the lack of skilled labor to operate AM equipment. Conversely, Tatham et al. (2015) argued that 3DP technology has a positive social impact as it mitigates logistical challenges during emergency responses; longer term, 3DP could lead to new industries in remote locations, giving a source of income to the poor, a situation Gress and Kalafsky (2015) called *spatial leapfrogging*. Moreover, Dumitrescu and Tănase (2016) argued that countries with trade deficits could exploit 3DP to offset this problem.

Using AM will help to solve ecological challenges such as scarcity of resources and pollution. This topic is becoming increasingly meaningful for business leaders (Bogers et al., 2016). However, more research is appropriate on the net overall effect on the environment of producing highly customized artifacts, layer by layer.

Consequences of additive manufacturing to business. Disruptive technologies, such as AM pose both a threat as offer opportunities to existing companies. Established value chains are affected and new business models initiated (Amshoff et al., 2015; Ortt, 2016; Rylands, Böhme, Gorkin, Fan, & Birtchnell, 2016). With AM, managers now can develop innovative business models (Rylands et al., 2016; Thiesse et al., 2015) and change, or even disrupt, current models (Bogers et al., 2016). Kianian et al. (2016)

revealed another benefit for companies deploying 3DP: the possibility to create end-products using substantially less material and time. These advantages enable firms to bring products to market faster than before (Kianian et al., 2016). Moreover, Soomro, Faullant, and Schwarz (2016) argued that AM enables value chains based on push instead of pull mechanisms.

Ford and Despeisse (2016) referred to Christensen's (2016) disruptive innovation theory and emphasized the importance of entrepreneurs to investigate different business opportunities that 3DP offers. Bogers et al. (2016) argued that incumbent firms need to examine AM’s potential for their organization and develop and test new business models. Mellor et al. (2014) pointed at the legacy of the use of AM for RP may create a psychological barrier to management when contemplating to utilize AM technology. Furthermore, Rayna and Striukova (2016) warned companies to investigate what business model they would like to deploy 3DP in before implementing this technology. AM reduces the number of assembly activities, requiring re-engineering of business processes (Thomas & Gilbert, 2014). Hence, Thomas and Gilbert posited, companies adopting 3DP are taking considerable risks, which impedes this technology’s level of diffusion.

Limited research exists on the industrial implementation of 3DP. Most literature focuses on consumers’ adoption of AM (Oettmeier & Hofmann, 2016c). Similarly, Thiesse et al. (2015) pointed out the lack of research on how AM affects management. Oettmeier and Hofmann emphasized the difference between the use of AM for RP and for industrial manufacturing. When practicing AM for prototyping, the focus is on computer systems and design methods, but when applied in an industrial setting, implementation and integration in the existing technological and organizational infrastructure is paramount (Oettmeier & Hofmann, 2016b).

Costabile, Fera, Fruggiero, Lambiase, and Pham (2017) emphasized the lack of research on the crucial aspect of understanding the total cost of producing items with AM and considered this gap in literature a barrier for further industrial AM adoption. Factors such as post-processing cost, quality issues, and machine utilization substantially affect the cost of 3D printed products (Schröder, Falk, & Schmitt, 2015). Notwithstanding the substantial flexibility AM offers to customize products, the benefit for mass fabrication of consumer goods is not always clear (Bogers et al., 2016). Often, uncertainty exists among managers about what business models and supply chains best support AM technology. For instance, moving production activities closer to, or even located at, consumers undermine the centralized production models and associated supply chains many firms use nowadays (Bogers et al., 2016). Furthermore, 3DP service companies have emerged and taken their place in the supply chain and companies' business models (Rogers et al., 2016). As this technology enables shifting centralized production to local manufacturing, Holmström et al. (2016) argued that DDM requires conventional operations management thinking, including supply chain management strategies. When developing such strategies, managers should also consider combinations of DDM with traditional manufacturing processes (Holmström et al., 2016).

Khajavi, Partanen, and Holmström (2014) researched the use of AM spare parts in F-18 Super Hornet fighter jets. Khajavi et al. discovered that the cost of AM equipment and operators at the time of the study were too high, and the production speed was too low for further expansion of AM in spare parts supply chains, but they also emphasized the risk third-party logistics service providers encounter of becoming obsolete when AM technology expands further. For example, the United States Navy is already experimenting with AM equipment onboard many some of their ships and Maersk is already using 3D equipment onboard their container vessels to produce plastic spare parts (Zanardini, Bacchetti, Zanoni, & Ashourpour, 2016). Fawcett and Waller (2014) echoed this stance and argued that leaders need to actively safeguard their companies against ever-faster-moving disruptions to avoid becoming obsolete. Conversely, Holmström et al. (2016) argued that traditional supply chain thinking such as multi-tier suppliers would be affected by DDM, and they posited that the question who will capture the financial benefits of local manufacturing by emphasizing the business opportunity for logistics service providers to enhance their business models by including local DDM.

Among the most prominent advantages of AM are advanced product designs and supply chains. For product design, Mashhadi et al. (2015) identified weight reduction, additional complexity, design freedom, and reduction of the bill of materials aspects. The most prominent benefits for supply chains are new business models such as selling the design instead of the product, customization or personalization, fewer suppliers, shorter delivery times, reduction of inventory, and transportation (Mashhadi et al., 2015). Resulting from the possibility to combine design with production, AM supports the concept of servitization of manufacturing and incumbents need to start to develop innovative business models (Brennan et al., 2015).

Torpid business models may represent a substantial threat to a firm’s existence when encountering technological disruption. Business models are the operationalization of companies' strategies and are often similar to most rivals (Tongur & Engwall, 2014). Tongur and Engwall developed a framework in which they recognized three aspects of a business model: value proposition, value creation, and value capture. Tongur and Engwall further argued that precedents exist of once famous companies not surviving technological disruption because they omitted to adapt their business model. Therefore, to survive, firms facing technology shifts need to proactively develop new strategies and business models: competitive advantage requires more than technological innovation only. Similarly, servitization is not the panacea against technological disruption either (Tongur & Engwall, 2014).

In the light of these technological shifts, how should businesses best respond? Tongur and Engwall (2014) emphasized the distinction between continuous and radical innovation whereby the first enhances competencies and the latter destroys them. Tongur and Engwall argued that historically companies responded to significant changes in technology by either changing their core competency or by servitization: exploiting the installed base of their products for additional sales or service. However, Tongur and Engwall further argued that because replacing a company's core technological competence is a daunting endeavor, a more effective response to technological disruption is by amending a firm's business model.

Conner et al. (2014) created a three-dimensional matrix to assist business leaders in determining if their products are suitable for 3DP and underpinned these dimensions with calculations. The three axes of this model consist of volume, complexity, and customization. From these dimensions, eight distinct areas emerged, each with a different level of suitability for creation by 3DP. First, mass manufacturing, which is not suitable for AM technology. Instead, using AM enables the production of small-series items, such as prototypes, products with advanced complexity, such as GE's aircraft-engine fuel nozzles, or mass complexity items such as hip replacement parts. Furthermore, using AM establishes the opportunity to create individualized products, such as luggage tags or spare parts, mass customization, or artisan products, for instance: Formula One-car components (Conner et al., 2014). Deradjat and Minshall (2017) discovered that the dental industry frequently uses AM for producing mass customized products. Finally, Conner et al. emphasized the complete manufacturing freedom AM offers (but they indicated that currently, no such demand exists).

Three-dimensional printing is expected to be more cost-effective than traditional manufacturing processes when fabricating products with increased levels of customization, complexity, or both (Conner et al., 2014). Wittbrodt et al. (2013) studied the economic feasibility of self-replicating 3D printers, called RepRaps. These machines are simple mechatronic devices that can reproduce approximately half of their components. When combining RepRaps with open-source CAD files, Wittbrodt et al. hypothesized that this technology would enable local manufacturing on a massive scale that will also considerably affect the way how people are using these products. Wittbrodt et al. postulated that families having RepRap printers could save many hundreds of dollars per year; the payback time of a RepRap varies between 2 and 24 months, resulting in a return on investment rate of 20 to 200%. Consequently, shifts from industry to home production pose a threat to incumbent firms as well as offer opportunities for entrepreneurs.

Every company, industry, or government must take a strategic position on what AM means to them (Beyer, 2014). Markides (2006) referred to Christensen's (2006) statement that disruption is a process, not an event; hence incumbents' best course of action sometimes is to wait and see. However, Sandström (2016) argued that having a business strategy, whether to wait-and-see or to adopt actively innovative technologies, both have their merits. Nevertheless, Holmström et al. (2016) warned practitioners and researchers to be alert. Although Holmström et al. did not expect DDM to replace mass and batch production shortly, they argued that many operations management activities, such as production planning and inventory management are likely to be affected or even become redundant. Similarly, Dumitrescu and Tănase (2016) mentioned that disruptive technologies influence how firms act towards their customers by offering novel and suitable manners to provide services or produce goods. Dumitrescu and Tănase argued that it took the Internet, a disruptive technology, almost 20 years to achieve maximum potential. Similarly, Dumitrescu and Tănase maintained that 3DP started a revolution that will change our lives, and they foresaw, similar to the proliferation of information on the Internet, AM technology will require only half this time.

Christensen (2106) gave illustrations of companies surviving during innovative disruptions, but he considered this as a proof most other firms perished following such occurrence. Markides (2006) arguments made Christensen realize that besides maximizing shareholder value, another fundamental responsibility of leaders is corporate survival, and in such a situation, inertness may be the right strategy to pursue. Nevertheless, managers should be aware of emerging disruptive threats to their firms. Therefore, the outcome of a survey McKinsey conducted in 2015 under managers of prominent manufacturing companies is alarming. The results showed 40% of respondents are unfamiliar with 3DP outside what they have read about it in the press, 5% believed that it does not apply to them, 12% want to learn more about AM, and only 10% of the respondents thought 3DP is relevant to them (Sasson & Johnson, 2016). Thus, Sasson and Johnson argued that managers need to consider the effect of 3DP to their business.

Transition

Section 1 provided the foundation for this study. I discussed the background of the problem, formulated the problem statement, purpose statement, and the RQ. Christensen’s theory of disruptive innovation was the conceptual framework used for the research. Next, I discussed the operational definitions, assumptions, limitations, delimitations, and significance of the study. Section 1 concluded with an extensive review of the pertinent literature. Section 2 will continue with the purpose statement, my role as the researcher, the participants and a discussion of the research method and design, population and sampling, and ethical research. I will also discuss the data collection instrument and techniques of data organization and analysis. The section will further include the reliability and validity of the study. Section 3 will include the findings and the results of this study, implications for social change, and recommendations for future research.

Section 2: The Project

This section includes the purpose of this multiple case study, my role as the researcher, and a description of the participants. Section 2 also contains discussions about the selected research method and design, population and sampling, and ethical research. Furthermore, I discussed data collection instruments, technique, organization, and analysis. The section continues with the methods used to ensure reliability and validity and ends with a summary and an overview of Section 3.

Purpose Statement

The purpose of this multiple case study was to explore strategies that light and high-tech manufacturing firm managers used to adopt AM technology into their business models. The target population included four individual managers, one at each of four different light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. The findings of the study may provide positive social change to business managers by providing strategies to grow their companies, which may lead to increased local employment and a more prosperous business community.

Role of the Researcher

I had a significant role in the data collection process of my study. Kirkwood and Price (2015) argued that all researchers should be aware of their research methods paradigm, their assumptions, and the limitations forming the basis of their investigations and supporting their conclusions. Researchers can be biased when they are related to the participants or the case (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). When collecting qualitative data, scholars act free of bias and acknowledge and report all personal and professional information that might influence the findings (Yilmaz, 2013). Furthermore, researchers are responsible for assuring their findings are reliable and valid (Kemparaj & Chavan, 2013). I deployed various strategies to alleviate the influence of personal bias by using an interview protocol (see Appendix A). This protocol included the interview and member checking processes and the interview questions.

I did not research the subject of this study before, and I do not have any previous relationship or engagement with any of the targeted companies or participants. I was researching this topic out of interest. However, obtaining prior information about the participants is essential when conducting case studies to develop an advanced understanding of the case (Yin, 2014). To have a better understanding of the target companies, I searched the Internet, used my professional network, and attended conferences.

During this study, I strived for the highest ethical standards. Therefore, I selected and designed this study, collected data, and approached participants following Walden University Institutional Review Board (IRB) requirements. IRB approval was required before conducting the study. In 1979, the Belmont Report was issued, outlining the ethical ground rules researchers need to comply with to protect vulnerable individuals (Brody et al., 2014). The IRB assures Walden students follow the three ethical principles of the Belmont Report: participants understand the risks and rewards of the study, participate freely, and are accurately informed (Brody et al., 2014).

When interviewing people in their daily circumstances, unexpected events might occur. Thus, preparing an interview protocol is necessary (Yin, 2014). These guidelines help to preempt unexpected situations, such as getting access to the venue, bringing sufficient interview resources, backup, a precise schedule, and contingency plans (Yin, 2014). Furthermore, the use of pre-prepared interview protocols assured consistency and helped to avoid omissions (Baškarada, 2014). Still, when using semistructured interviews, those protocols should allow for ensuring sufficient flexibility exists to alter the sequence of the questions asked or expand more on ideas emerging from the meeting (Baškarada, 2014). Another method of reducing bias is electronic recording and transcribing the interview verbatim (Houghton, Casey, Shaw, & Murphy, 2013). Applying these strategies assisted in reducing personal bias that I may have inserted in this study.

Participants

The participants selected were managers of light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. Selecting suitable candidates is essential when conducting case studies (Yilmaz, 2013). First, I searched the Internet and social media platforms such as Facebook or LinkedIn, and public documents to identify companies that have used successful strategies for adopting 3DP technology and obtained contact details of the responsible managers for this technology. Using the internet and social media is a useful approach for researchers to identify participants (Burke, Fish, & Lawton, 2015; Khatri et al., 2015). Next, I sent these managers an invitation letter. Upon confirmation of the participant’s participation, I sent them an informed consent form for their perusal and signature. When researchers use consent forms, participants understand their cooperation is voluntary, and know how interviews are conducted and recorded (Doody & Noonan, 2013).

Establishing and maintaining a positive working relationship with participants is essential when conducting case studies (Seitz, 2016; Yilmaz, 2013). Close relationships and trust between participants and the researcher ensure their retention (Polese, de Faria-Fortini, Basílio, Faria, & Teixeira-Salmela, 2017). Therefore, I maintained regular contact with the confirmed participants throughout this study. During the interview process, I continued to establish a professional working relationship with participants.

Research Method

Three research methods are at scholars' disposal for conducting studies: qualitative, quantitative, and the mixed method (McNulty, Zattoni, & Douglas, 2013; Salvador, 2016). A critical aspect to consider when selecting an appropriate research method for a study is the researcher's worldview or paradigm (Collis & Hussey, 2014; Yilmaz, 2013). I have a preferred learning style for interpretive, inductive methods. Qualitative research is an appropriate method for researchers having such learning preference (Khan, 2014; Yilmaz, 2013). Qualitative researchers consider the study topic and the environment and aim to create a connection between the researcher and the subject studied (Bailey, 2014; Kemparaj & Chavan, 2013; Yilmaz, 2013).

Qualitative research methods are becoming a more popular approach (Hyett, Kenny, & Dickson-Swift, 2014) and are often used in management studies (Brewis, 2014) as researchers using this method attempt to answer *how*, *why*, *what*, *where*, and *when* questions (De Massis & Kotlar, 2014). When limited research exists on significant issues, an inductive study is preferred (Eisenhardt et al., 2016; Koch, Niesz, & McCarthy, 2014). Considering my research paradigm and the actuality of this research topic, selecting a qualitative method was the best choice. Within the qualitative research method, many designs exist.

Quantitative researchers endeavor to explain phenomena statistically based on numerical data (Salvador, 2016; Yilmaz, 2013) between two or more variables to generalize about a population (Tsang, 2014). Quantitative research is most suitable for positivist researchers because of the relationship between developing and testing hypotheses (Collis & Hussey, 2014; Morse & McEvoy, 2014). Limited research exists on the research topic for this study; therefore, insufficient numerical data was available to test a hypothesis. Considering my interpretivist research worldview, a quantitative methodology would not have been appropriate for this study.

In mixed method studies, researchers combine quantitative and qualitative research into a single study (Yin, 2014), combining both research paradigms (Tsang, 2014). Combining these two approaches generates a higher level of understanding of a phenomenon (Salvador, 2016). Despite this potential benefit, mixed method research was not suitable for this study as I did not test hypotheses or collect numerical data.

Research Design

A research design outlines the framework for the main components of a study: what to ask, which data to collect, and how to evaluate this data (Yin, 2014). With the qualitative research approach, the most common designs are case studies, phenomenology, or narrative inquiry (Collis & Hussey, 2014; Dixon, 2015; McNulty et al., 2013). An exploratory multiple case study is a suitable research design to explore a phenomenon (Dixon, 2015; Houghton et al., 2013; Yin, 2014). In my study, I attempted to answer *how* or *what* questions on a complex contemporary phenomenon. Cronin (2014) argued that using case studies generates a wealth of experience and allows readers to view the study through the eyes of the researcher, thereby creating more acceptance of the research conducted. Hunt (2014) posited that place and time bind case studies and Hyett et al. (2014) believed that case studies are more flexible than most other qualitative designs.

Other qualitative designs may include ethnography, phenomenology, or narrative research. Narrative inquiry aims to tell the story of a single individual, or the lived experience of small groups with a phenomenon (Bevan, 2014; Hunt, 2014). Zavattaro, Daspit, and Adams (2015) indicated that narrative inquiry is a suitable design for investigating what happened retrospectively, mainly in relation to complex real life social problems. Phenomenology is a philosophical approach to study the meaning of an event (Darawsheh, 2014; Yilmaz, 2013; Zahavi & Simionescu-Panait, 2014). This design includes studying an individual’s or group of people’s shared and lived experiences with a particular phenomenon (Hunt, 2014; Moustakas, 1994; Zahavi & Simionescu-Panait, 2014). The purpose of phenomenological research is to inform the public of a certain experience involved persons have had with an occurrence (Moustakas, 1994). This research design originates from anthropology (Collis & Hussey, 2014). Ethnography involves direct observation of subjects in the field (Moustakas, 1994), such as cultural groups in their natural environment (McNulty et al., 2013; Salvador, 2016). I did not select a narrative design because I did not gather stories from individuals about their lived experiences. Phenomenology was not suitable for this study, as I did not study human experiences of events in real -life settings. Ethnography was not an appropriate design for this study because I did not study the culture of groups of people or observe people.

A method to increase the validity of a study is methodological triangulation by data saturation. Data saturation originates from grounded theory, but it also applies to case studies (Cleary, Horsfall, & Hayter, 2014). When researchers obtain sufficient information for their study to be replicated and no additional information can be acquired, they achieve data saturation (Fusch & Ness, 2015; Houghton et al., 2013; Robinson, 2014). Saturated data consist of information that is both rich, meaning high quality, and thick, meaning large quantity (Fusch & Ness, 2015). I achieved data saturation when no new and meaningful information surfaced within the limitations of this study.

Population and Sampling

The population of this study included managers of light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. When conducting case studies, selecting interviewees is a crucial step to assure they have the right experience with the research topic (Elo et al., 2014; Katz & Vinker, 2014; Yin, 2011).

I used purposeful sampling for this study. Elo et al. (2014) and Kaczynski, Salmona, and Smith (2014) indicated that no set rules exist to decide the sample size for a case study. Purposeful sampling to select suitable candidates from this population is a successful strategy (Kemparaj & Chavan, 2013; Yilmaz, 2013). Ishak and Abu Bakar (2014) argued that purposeful sampling is appropriate when researchers: (a) wish to select particularly interesting cases, (b) want to include members of specialist groups, and (c) wish to select specific case types to study more intensely.

Based on the principles of purposeful sampling, I used a sample size of four participants, one each from four different companies. Yin (2014) argued that sample sizes of two or three are adequate for multiple case studies where no utmost certainty is required. Deradjat and Minshall (2015) and Wilhelm, Blome, Bhakoo, and Paulraj (2016) used sample sizes of four companies for their multiple case studies. Malterud, Siersma, and Guassora (2015) argued that in qualitative research the sample size depends on the amount of information the participant possesses, rather than on mathematical formulas.

By interviewing four participants and reviewing documents such as business plans, reports, meeting minutes, memos, e-mails, organizational charts, or market surveys, I expected to achieve data saturation. However, I continued interviewing more participants and reviewed more documents until no new information emerged. In case studies, obtaining quality data through rich description is more important than acquiring thick data through larger size populations (Morse, 2015; Palinkas et al., 2015).

The criteria to participate in this study were to be a manager of light and high-tech manufacturing companies in the Netherlands who had used successful strategies to adopt AM technology into their business models. Consequently, these participants had adequate knowledge for answering the interview questions. Interviews with participants took place in a private setting, such as the participant's work office.

Ethical Research

Ethical considerations are essential when conducting research (Yin, 2014). Thus, Walden University has established an Institutional Review Board. Therefore, I treated all participants ethically. Participation in this research was voluntary. I did not offer any incentives except for a summary of my study upon completion. Informing participants that they have the right to withdraw from the study at any time without retaliation is essential (Dekking, Van der Graaf, & Van Delden, 2014). I provided all participants my Walden e-mail address and mobile phone number in case they wished to withdraw. All participants could withdraw from this research by informing me verbally, by telephone, or by e-mail. When participants withdrew from the study, I destroyed all the information related to them.

For this study, I obtained IRB approval (01-05-18-0611752). Next, I submitted invitation letters and consent forms to all potential participants. In the invitation letters, I explained the purpose of my study and my expectations of the participants, and I assured the confidentiality of all participants.

Newman and Glass (2014) emphasized the importance of keeping participants safe, maintaining the information they provide confidential, and assuring their privacy stays secured. Thus, I assigned all companies a code C1, C2, C3, and C4 and all participants codes P1, P2, P3 and so on, based upon the sequence of my receipt of their letters of consent. Following Walden’s IRB approval, I kept all business and personal information safe and secure. I archived electronic files in a password protected hard drive and keep all written information and the hard disk in a safe. Khan (2014) recommended maintaining full confidentiality of all participants in this study. I ensured the confidentiality of my participants. After 5 years, I will destroy all files on the hard disk and shred all documents using a paper-shredding machine.

Data Collection Instruments

When conducting qualitative studies, the researcher is the primary research instrument for data collection (Chereni, 2014; Koch et al., 2014; Olson, Appunn, McAllister, Walters, & Grinnell, 2014). As the primary research instrument in my study, I conducted semistructured interviews, member checking, and reviewed company documents on strategies used for adopting AM technology into business models.

Interviews support obtaining a thorough understanding of a phenomenon through the perspective of the participant. Townsend and Cox (2013) used semistructured interviews with open-ended questions for their studies. I also used this tool. The interviews took place either at participants’ offices or other private locations convenient to them. Interviews lasted between 60 and 90 minutes. Baškarada (2014) and Faseleh-Jahromi, Moattari, and Peyrovi (2014) argued that using interview protocols and recording the interviewee's answers are excellent ways for the researcher to collect data. Therefore, I utilized an interview protocol (see Appendix A) with semistructured questions as a secondary data collection instrument. I audio recorded the interviews and participants’ responses with an electronic voice-recording device for easier transcription.

In addition to interviewing and document collection, I made notes during the interviews to capture thoughts, observations, and findings and use these as a data source for the case study. Anney (2014), Lawrence and Tar (2014), and Yin (2014) advised note taking as a sound researching practice when conducting qualitative research. When conducting qualitative research, methodological triangulation is appropriate for validating the case study construct (Fusch & Ness, 2015; Joslin & Müller, 2016; Yin, 2014).

Member checking is a strategy used in qualitative research to increase the quality and rigor of studies (Cope, 2014; Houghton et al., 2013; Yilmaz, 2013). To maintain rigor with my study, I used a company to transcribe the interview responses, scheduled a telephone call with participants, provided participants with a summary of the interview responses, and then verified with them if my summary and interpretation of the responses were accurate. I also probed for more information and asked follow-up questions regarding the interview and the documents provided. Black, Palombaro, and Dole (2013) advised about keeping an audit trail to support validity. Therefore, I followed this recommendation by keeping a reflective journal.

Data Collection Techniques

Some data collection techniques available to case study researchers are reviewing documents and conducting interviews (Yilmaz, 2013; Yin, 2014). The data collected for this study included semistructured interviews and documents. The primary data collection technique for qualitative studies are interviews (Janghorban, Roudsari, & Taghipour, 2014; Koch et al., 2014). By audio recording interviews, novel researchers can establish a database suitable for efficient transcription (Doody & Doody, 2015). To assure consistency and enhance the reliability and validity of this study, I used an interview protocol (see Appendix A). Interview protocols are a valuable tool for reducing researcher bias (Yin, 2014) and enhance research reliability (Morse, 2015). Furthermore, such protocols assist in explaining the structure of the interview process to the candidates, and they also serve as a procedural guide for the researcher (Yin, 2014). The interview protocol contained an opening statement, an introduction of the researcher and an explanation of the purpose of the study, a description of the interview and member checking processes.

The benefit of conducting semistructured interviews over open-ended interviews was that they support the collection of rich data and give the researcher some flexibility and the possibility to ask for clarification (Cleary et al., 2014; Doody & Noonan, 2013; Yang & Wu, 2014). Despite their popularity, Doody and Noonan pointed out that conducting interviews has challenges, including higher cost, the longer time it takes to perform them, and the possibility to insert bias researcher do not correctly formulate interview questions.

The interviews took place at a time and location convenient to the participants. I asked the participants to sign the consent form. I confirmed each interview appointment through an MS-Outlook calendar invitation and sent a reminder 24 hour before the event. The allocated time for the interviews allows for additional questions or remarks from the participants.

The data collection process included making electronic recordings of the semistructured interviews using an electronic voice-recording device. In addition, I made handwritten notes of my observations of the participant’s body language or additional content. Making notes is an essential source of qualitative data collection (St. Pierre & Jackson, 2014). Furthermore, I electronically scanned all paper documents participants will provide me with to enhance data analysis. For member checking, I contacted participants via telephone to conduct a second interview, which consists of providing a summary of interview responses to participants to make sure my interpretations of their interview responses are accurate and to pry for any additional information.

In addition to the interviews, I collected company documents on strategies used to adopt AM technology into business models records that participants gave me. Documentation is a primary source for case study data as researchers do not create them as part of a study, they do not change over time, are specific and comprehensive (Yin, 2014). However, collected documentation might be biased, difficult to acquire, or selectively provided by candidates (Yin, 2014).

Data Organization Technique

Management and organization of data are paramount for well-conducted case studies (Yin, 2014). The first part of the data organization occurred with the categorization and archiving of all literature used for this study in Mendeley desktop. Mealer and Jones (2014) argued that researchers should not disclose participant information on their study data. Therefore, I removed all identifiable information from interviews and notes to protect interviewees' identities. After each interview, I downloaded the interview recordings, scanned all the notes and uploaded documents to my laptop. I created a backup copy on an encrypted removable hard disk. Subsequently, I labeled all transcriptions of the interviews and notes with unique codes. I stored all physical documentation, such as brochures and plans, together with the hard disk in a locked safe to assure confidentiality of the participants. I also required the company conducting the interview transcriptions to sign a confidentiality agreement. Using safes and password protected electronic storage is essential to guarantee participant confidentiality (Mealer & Jones, 2014). Following, I manually coded, sorted, filed, and analyzed all the collected data. Woods, Paulus, Atkins, and Macklin (2016) suggested utilizing qualitative data analysis software (QDAS) to support data analysis and organization. Therefore, I operated QDAS to keep track of all data, support data organization, and analysis. According to University requirements, I will destroy all files on the hard disk and all related documents after 5 years.

Data Analysis

When qualitative researchers want to have a deeper understanding of a phenomenon, they use various methods of triangulation (Carter, Bryant-Lukosius, Dicenso, Blythe, & Neville, 2014). Yin (2014) recognized four types of triangulation: triangulation by using various sources of data, by having various researchers, by considering different conceptual frameworks, or triangulation through different research methods. For case studies, methodological triangulation using multiple resources to collect data is the most appropriate way for researchers to corroborate their findings (Anney, 2014; De Massis & Kotlar, 2014; Yin, 2014) and enhance the quality of the study (Yilmaz, 2013). Therefore, I used methodological triangulation to collect data and ameliorate the validity of my research findings. For this study, I collected data from various sources conducting semistructured interviews, company documents, and additional information obtained from member checking. Transcribing all interview recordings, checking them against the original recordings, and making corrections where necessary is critical (Townsend & Cox, 2013).

Yin (2011) recommended a five-step process for case study data analysis: (a) compiling the data, (b) disassembling the data, (c) reassembling the data, (d) interpreting the data, and (e) concluding. When I analyzed the data, I applied Yin’s five-step approach to collect data, disassemble data, reassemble data, and then comprehend it so that I could complete my findings. Data analysis includes manually analyzing and comparing the data collected from interviews, member checking, company documents, and next putting this data into emerging themes (Townsend & Cox, 2013). Faseleh-Jahromi et al. (2014) called this process: constant comparative analysis. I used Yin’s (2011) five-step process to collect and analyze data acquired from my interviews, member checking, and review of documents and then organized this data into emerging themes. This process included comparing and contrasting data or constant comparative analysis. Once I determined the themes, I correlated them to content in my literature review and theory in my conceptual framework. In this study, I applied the conceptual framework of Christensen’s (2016) theory of disruptive innovation to support my findings. Such a strategy is a conventional method used by researchers (De Massis & Kotlar, 2014; Yilmaz, 2013; Yin, 2014).

Many scholars conducting qualitative research used QDAS to analyze and organize their collected data. For example, Neuman (2014); Paulus, Woods, Atkins; Macklin (2015); and Woods et al. (2016) used QDAS. Using QDAS increases the reliability of a case study as it enables others to review the case study database (Yin, 2014). For this research, I selected Atlas.ti as QDAS to assist in the organization, assessment, querying, matching, and explanation of the collected data to develop themes.

Reliability and Validity

The quality of social studies, such as case studies, needs to be verifiable (Yin, 2014). Four standard methods exist to check the design of a study: construct validity, internal validity, external validity, and reliability (Houghton et al., 2013). In qualitative research different terms are often used: dependability, credibility, transferability, and confirmability. In the following subsections, I will describe how I ensured reliability and validity or in this case study. First, I will explain how I established this study's reliability.

Reliability

Reliability or dependability of a study relates to the stability of the data (Houghton et al., 2013), or more precise: it discloses how well researchers, through their study, depict an actual cognizance of the subject studied (Yilmaz, 2013). The purpose of dependability is to enable future researchers to achieve the same results using the study's data. Despite, it is not possible to replicate a case study (Morse & McEvoy, 2014).

Yin (2014) argued that describing in detail how to design and conduct a study is essential. Recording all steps taken and decisions made during the study are paramount for establishing an audit trail (Cope, 2014; Houghton et al., 2013; Morse, 2015). Using a QDAS further supports the auditability of a study (Houghton et al., 2013; Kaczynski et al., 2014; Woods et al., 2016). Another method of enhancing the quality of a case study is note taking (Charach, Yeung, Volpe, Goodale, & Dosreis, 2014; Houghton et al., 2013; Hurst et al., 2015). Therefore, I carefully described the RQ, used an interview protocol, documented each decision made, electronically recorded and transcribed the interviews, conducted member checks, took notes, and utilized QDAS to archive, organize, and analyze all research data collected. Additionally, including thick description enhanced the auditability and replicability of the study (Anney, 2014; Houghton et al., 2013; Morse, 2015). Besides reliability, research validity is another essential attribute of a case study, as discussed hereafter.

Validity

Generalizability, internal validity, reliability, and objectivity determine the validity of research (McNulty et al., 2013). With qualitative studies, the level of credibility, transferability, and confirmability the researcher demonstrates determines its validity (Yilmaz, 2013). Credibility is a concern when conducting explanatory case studies (Yin, 2014). When participants in qualitative research acknowledge the results of the study, credibility is assured (Yilmaz, 2013). Credibility may be achieved by using triangulation or member checking (Anney, 2014; Carter et al., 2014; Yilmaz, 2013). Furthermore, credibility can be enhanced by providing thick and rich description (McNulty et al., 2013), or by reflexivity (Anney, 2014; Berger, 2015; Darawsheh, 2014).

Related to dependability, Houghton et al. (2013) argued that the confirmability of a case study means the data is unbiased and accurate. Furthermore, audit trails, reflexibility, and triangulation are critical facets of confirmability (Anney, 2014). Following these strategies, I used rich quotations from the interviews when making interpretations and drawing conclusions, to assure confirmability. Cope (2014) used such an approach.

Transferability is a significant aspect of qualitative research. Transferability relates to the ability of others to understand the findings and apply them in their natural setting (Cope, 2014; Houghton et al., 2013; Yilmaz, 2013). Applying rich and thick description (Black et al., 2013; Kemparaj & Chavan, 2013; Yilmaz, 2013) and including participants' quotations (Elo et al., 2014; Houghton et al., 2013) facilitates transferability.

Data Saturation

Fusch and Ness (2015) argued that researchers might achieve data saturation by obtaining sufficient information and no new information is available so that others can replicate their study. Morse (2015) argued that conducting semistructured interviews leads to earlier saturation of data than when using unstructured interviews. For this study, I continued interviewing and reviewing documents to the point where no different and meaningful information surfaced and repeated the constant comparative method until no additional themes emerged.

Transition and Summary

In Section 2 of this study, the research process was outlined. First, I explained the role of the researcher and the strategy to obtain access to the participants, which was then followed by the research design and methodology. Further topics discussed included the population and sampling processes and how to assure ethical compliance with the IRB. Subsequently, I explained the data collection, organization, and analysis processes. Section 2 finished with a discourse about the reliability and validity considerations of this study. In Section 3, I will present the findings and discuss the applications to professional practice and implications for social change. In addition, Section 3 will conclude with recommendations for actions and future research and provide reflections on this study.

Section 3: Application to Professional Practice and Implications for Change

In this section, I present the findings from my research study, relate the content from the literature review and conceptual framework to my findings, and compare my findings to those of other research studies. Section 3 consists of the presentation of the findings, applications to professional practice, implications for social change, recommendations for actions, suggestions for further research, and reflections. The section ends with a summary and the conclusions from my study.

Introduction

The purpose of this qualitative case study was to explore successful strategies that light and high-tech manufacturing firm managers used to adopt AM (AM) technology into their business models. From the data that I collected and analyzed, the findings revealed three significant themes regarding such strategies that are presented here.

Presentation of the Findings

The overarching RQ of this study was: What strategies did light and high-tech manufacturing firm managers use to adopt AM into their business models? The three major themes that emerged from the data were: (a) identify business opportunities for AM technology, (b) experiment with AM technology, and (c) embed AM technology.

Theme 1: Identify Business Opportunities for Additive Manufacturing Technology

Slack and Lewis (2015) pointed at the difficulty companies encounter understanding targeted market requirements and coupling these with their future operational resources. To make this effort even more complicated, Demil, Lecocq, Ricart, and Zott (2015) pointed at the importance of understanding customers' *latent* requirements whereas Christensen and Raynor (2003) emphasized that companies formulating strategies should endeavor to understand how and under what circumstances customers use items, not focus on the customers themselves.

Triggered by the substantial attention 3DP received in the media, participant companies had all considered using AM technology, as they believed that using this technology would give them a competitive advantage. The first step a company should take in the development of a technology strategy is understanding the marketplace for the planned investment (Khorram Niaki & Nonino, 2018). Mellor et al. (2014) postulated that the type of market and products determine investment decisions in AM. Market forces, structures, drivers, opportunities, and positions feed into the strategic decision-making process (Stacey, 2011). In line with previous research, the first theme to emerge, identify business opportunities for AM technology, had two subthemes: (a) understanding the market that valued such advantages, and (b) conducting market research to identify competitive advantages, such as technical opportunities, cost-saving opportunities, and lead time reduction.

Market structure. C1 is a value-added logistic company. C2, C3, and C4 are contract manufacturers: C2 serves the medical implants sector, and C3 operates as a traditional machine shop, serving various industrial sectors. C4 is a spin-off from a ceramics parts maker, dedicated to additive contract manufacturing as well as developing AM equipment, also serving the medical implants and tools sectors. The participant companies acknowledged the importance of thoroughly understanding the market forces.

All participant companies identified markets where customers would value some of the unique characteristics of AM: low volume, high complexity, customization, or short production time. Furthermore, as Ortt (2017) and Weller et al. (2015) predicted, all those customers operate in or supply to niche markets: the medical implants and tools sector, Formula One race cars, spare parts, racing yachts, and aerospace parts. Besides the medical sector, which is willing to pay higher prices for low volume items made with traditional subtractive manufacturing techniques, such niche markets are often ignored as traditional equipment setup cost would be too high (Rayna & Striukova, 2016). In such markets, adopting AM might offer a competitive advantage (Weller et al., 2015).

Firms operating in more traditional markets experienced limited customer interest in products made with AM. P3 experienced that clients often do not understand what to do with 3DP; their engineers do not have the right mindset to consider the benefits of AM and often dismiss the technology as they see it as a threat to their position, whereas buyers expect a lower price. P4 blamed this inertia mostly on the reluctance of senior engineers “The speed of adoption is the speed by which engineers are prepared to consider applying AM . . . no client was pushing us to start with 3D printing.” Consequently, C3 mostly has new customers for their AM equipment as they believed that there is not much that they can offer existing customers; although this was their original intent. Slowly, their AM capabilities generated more business from new clients. Understanding the marketplace is essential because the specific demands of individual industries also influence the implementation of AM. For example, P3 pointed out that aviation is a good growth market for AM, but not for traditional machining because of its stringent quality management requirements.

P2 emphasized the importance of conducting thorough market research when considering implementing AM. P2 argued that it is a misconception that you can buy a 3D printer and then new business will come automatically. Metal 3DP is complex. P3 confirmed this stance when explaining that C3 decided to acquire AM equipment as a new technical competence but later discovered that their existing customer base hardly was interested in this technology.

Market research. Understanding the market and the forces governing it is an essential aspect of strategy formulation and business model innovation (Demil et al., 2015). To understand the threats and opportunities that AM posed to their firm, C1 sponsored a master's thesis study on the threats and opportunities of AM to their firm. Based on this study, C1 decided to acquire 3DP equipment, sought close cooperation with a 3D modeling company, hired an AM specialist, and set up a test lab where they, jointly with customers, could experiment with this technology to identify business and technical opportunities.

C2 serves the high-tech, oil and gas, medical, and aviation industries. After conducting their in-depth market studies for clients' possible interest in using AM technology, the company decided to focus on the medical sector. From publications, conversations, and tradeshows P2 learned that this sector was particularly interested in specific technical aspects of AM, mostly titanium products with an open-mesh structure and a rough surface. P2 stated, "I don't know any of our customers who are not working on 3D printing." P2 further explained, "Clearly we saw our customers move in that direction and you didn't see this in high-tech and oil and gas sector. This was and is the main driver." P4 explained that their decision to embark on a strategy of adopting AM stemmed from curiosity: "We heard the noise, trade journals wrote about it, and we saw a lot of materials except for ceramics. Then we became a little curious."

Competitive advantage. To establish a sustainable competitive advantage, manufacturing firms need to develop capabilities that competitors cannot easily replicate (Slack & Lewis, 2015). Contrary to 3DP hubs, whose core capability is to produce a plethora of items using specific AM equipment, existing firms adopting AM into their business models can offer a blend of flexible manufacturing together with their existing competencies, thereby offering a unique selling proposition.

To attract clients' attention in 3D printed products, firms implementing AM need to emphasize to customers the benefits of using this technology: (a) freedom of design, enabling customers to design shapes that otherwise would be impossible to manufacture; (b) reduced lead times; (c) cost reductions; (d) customization; and (e) technical possibilities. Potential technical possibilities include open-mesh structures and rough surfaces, desired by the medical implant sector, or weight savings, paramount for the aviation and speed racing industries. Furthermore, niche markets often require low volume, high complexity items (Ford et al., 2016). Other benefits of AM are simplified supply chains and local production possibilities (Thomas & Gilbert, 2014).

As most participant companies are machining shops, they can also offer surface finishing of products made by AM, as a one-stop shop; a competitive advantage over a 3D-printing hub. Thus, as a value-added logistics service provider, C1 can offer a combination of supply chain management and AM services. In such hybrid manufacturing models, the advantages and disadvantages of the existing and new technologies are more balanced (Newman, Zhu, Dhokia, & Shokrani, 2015). A traditional process for manufacturing complex shapes is molding, sand casting, and lost-wax casting, processes not designed for fast delivery, small quantities, shape modifications, or customization (Conner et al., 2014). AM is an alternative technology that solves these constraints. P1 stated, “I think 3D printing should be seen as a replacement for casting rather than milling or machining.” P3 echoed this stance “Small series with faster delivery times . . . you can design differently or can design hollow or easier, for example, to create a kind of sloping surface. Sometimes it is . . . about the small runs or faster delivery times.” When a potential customer approached C1 asking whether they could produce a spare part for a production machine, P1 recognized the opportunity. C1 delivered the replacement part quicker and cheaper, resulting in customer satisfaction.

Another opportunity that the use of 3DP enables is the possibility for high levels of customization. Eggenberger, Oettmeier, and Hofmann (2018) mentioned the plans some car makers have for customization of their vehicles. Although not everyone in C1’s organization initially supported the idea, P1 recognized the potential role that C1 could facilitate in such a future supply chain. P1 explained

> Our customers in this exploration say “Our future thought is to build a basic car, with fifty to sixty parts, which are 3D designed, which are replaceable. In color, shape, material, etcetera.” So, they sell a car, once, but they can sell the fifty to sixty spare parts thousands of times every year. . . . Because you have new shapes, new dashboards you can- if you have a midlife crisis- you can change your basic

car into a sports car because it is possible.

When asked how its automotive customers responded when a logistic service provider proposed to manufacture and supply 3D printed parts to them, P1 replied that these clients were amazed that they could discuss the technological aspects of 3DP with them. C1 demonstrated its aptitude for providing a solution to customer's problems, even problems their clients had not yet thought of. One of the first successes C1 had with AM was producing a spare part for a food production machine at 60% lower cost while simultaneously solving a customer supply problem.

AM is a production technology whereby an item is created layer by layer, based on an electronic 3D model directly from raw materials, such as powders, liquids, sheets, or filaments (Kellens et al., 2017). Using this technology, items can be made with a complex geometry that cannot be made with traditional techniques or only at considerable cost (Gutowski et al., 2017). Furthermore, items made with AM can be lighter (Mami, Revéret, Fallaha, & Margni, 2017) and stronger (Duchêne et al., 2016), and require fewer assembly activities (Thomas & Gilbert, 2014).

For C2, the open honeycomb structures that are possible using AM, combined with the rougher surface that comes naturally with 3D printed products, was an outstanding technical opportunity for producing medical implants. P2 added, "Three-dimensional printing does not reduce labor cost; the benefit lies in creating structures that cannot be made with other techniques."

To optimally benefit from the geometric freedom of AM, products need to be designed for use with this technology. Therefore, existing components often require redesign (Klahn, Leutenecker, & Meboldt, 2014). However, design engineers need to have a thorough understanding of the aspects of AM (Klahn, Leutenecker, & Meboldt, 2015). When existing parts are redesigned for AM, they may be sold at higher prices, outweighing the higher production cost (Eggenberger et al., 2018). Current design methods are mostly based on subtractive manufacturing methods, limiting engineers' creativity (Salonitis & Al Zarban, 2015). P4 lamented that "80% of the applications they receive are not designed for 3D printing." P2 echoed this issue by pointing out that C2 often received customers' requests for proposal for reproducing existing items with AM at a lower cost. Such requests never led to success because the benefits of AM mostly lie in producing items with designs optimized for 3DP.

A change in the education of engineers to equip them with the skills to functionally design items is an essential factor for the successful diffusion of AM technology (Gausemeier, Echterhoff, & Wall, 2012). P2 said that

> Essential is, in schools, it is starting to emerge: to make engineers familiar with the possibilities of 3D printing . . . on the drawing board, with the engineers, parts need to be designed with the possibilities of 3D printing, these aspects have to be applied then and not by transferring existing technologies to 3D printed products. . . . It should really be part of the technical curriculum: the possibilities and impossibilities of 3D printing before expanding to mainstream.

Mellor et al. (2014) already pointed out that the lack of experience product designing engineers have with 3DP is one of the significant barriers to AM technology adoption. The examples P2 and P4 gave confirmed Mellor et al.'s arguments.

Theme 2: Experiment With Additive Manufacturing Technology

Extensive experimenting with AM technology emerged as the third theme. Companies often tryout new technologies before they decide to adopt them (Rogers, 2003). The U.S. Department of Commerce stated that

> Large firms adopting AM spent considerable resources and efforts studying how to use these technologies, how to optimize them to meet their own production and legal requirements, and how to test the products made by these technologies to integrate them into their overall production. However, due to the lack of adequate measurement science, all these usually are accomplished by empirical trial and error procedures. Therefore, any simple modification in materials, design, or end use requires them to go through costly efforts for finding optimal solutions. (NIST, 2013, para. 13)

Funded by the federal government, the America Makes program was created to assist small and medium-sized enterprises (SME) with AM-related research and development, collaboratively with other companies, universities, and not-for-profit organizations; similar programs exist in Singapore and the United Kingdom (Go & Hart, 2015) and China (Y. Huang, Leu, Mazumder, & Donmez, 2015). Although the European Union funded similar initiatives, currently no AM collaborative experimentation program exists in the Netherlands. Therefore, the participant firms, Dutch SMEs that made a strategic choice to implement AM, had to develop a trial and error approach themselves.

All firms participating in this study conducted extended experimenting with 3DP technology. Such experimenting varied from testing which type of AM technology and which type of equipment were most suitable for the intended use, to trying to thoroughly understand the manufacturing process, such as the correct setting of the equipment, the right speed, the proper placing of items on the machine bed and so on. The experimenting either took place internally, individually, or jointly with customers, suppliers, partners, or government agencies or externally in the form of a joint experimentation laboratory.

Three subthemes are buttressing theme 2: internal piloting, joint internal piloting, and joint external piloting. These subthemes represent a crucial step in these firms' implementation of 3DP. All subthemes will be discussed in detail, henceforth.

Individual piloting. Contrary to a collaborative process of knowledge transfer, C1 and C3 followed an individual experimenting approach with AM technology. C1 purposely decided to establish an exploration lab. Through this lab, C1 explored the opportunities that 3DP could bring, attracted potential customers' attention to the possibilities of using AM for solving their supply chain challenges, and produced some spare parts. C1 procured two Ultimaker 3D and one Formlabs desktop printers and used a third party for 3D software modeling; metal parts are outsourced to 3DP equipment manufacturers. Together with some customers, C1 endeavored to replace existing parts with 3D printed ones.

C3 took a different approach: following its management's decision to buy a metal printing machine to complement the existing manufacturing capabilities they had to test the new equipment themselves in a production environment. This experimenting took place in the form of heuristics. In hindsight, P3 would have preferred to conduct a pilot project before selecting a specific AM equipment brand and learning by trial and error during operations: “I think it would have been better for us if we had a pilot phase because … I do not know if we have had a pilot phase we would have chosen the same equipment.” Next to single firm experimentation with 3DP technology, the participants also joined forces with partners in trial-and-error the new technology.

Joint internal piloting. C4 decided to conduct piloting in-house, together with third parties. With support from their parent company and ECN, a government innovation research center, a separate entity was established where the experimenting with AM ceramic materials took place. The parent company provided knowledge of ceramic materials and project management capabilities, ECN provided their knowledge of light and chemicals, and a third party developed prototype machines. All people involved were long-term acquaintances, which helped to keep the team together and make fast progress. Another form of probing the innovation is in a collaborative piloting group, as C2 did.

Joint external piloting. Contrary to the internal experimenting that C1 and 3 conducted, C2 joined an initiative for a joint pilot program, called AddLab. Eight firms formed AddLab, consisting of machining companies, a 3DP hub, networking and financing organizations. The annual participation fee was relatively small (100.000 euros a year). In this lab, C2 could experiment with different AM equipment and materials to identify the most suitable 3DP solution for their needs and learned how to utilize 3D technology. After the completion of the joint piloting program, only C2 and another manufacturing firm decided to adopt 3DP in their production process; other pilot partners established a joint AM production facility, called AddFab.

The main benefit of joint piloting in AddLab was, as P2 said “The possibility to test various types of [AM] technology and transfer knowledge between the participants at limited financial investment. It was a responsible playground to test the state of the technology regarding hardware and software." Furthermore, following the piloting phase and understanding the severity of requirements for medical implants, P2 collaborated closely with its clients developing AM capability "unless if you decide to operate in the prototype market only, you have to closely cooperate with your customers."

Customer involvement. One of the main benefits of AM is the freedom of design. Chiu and Lin (2016) emphasized the importance of early customer involvement with AM product design. However, because the participating firms either are contract manufacturers or value-added logistics service providers, product design lies outside their area of responsibility. Notwithstanding, early customer involvement often is used by firms to attach clients to a firm (Van der Zee et al., 2015).

Two participant firms involved their clients in the newly adopted technology. The phase when those customers participated and the depth of their role varied across the participants. P1 organized a workshop with some of its customers to identify bottlenecks in their supply chains for which AM could offer a solution, followed by pilot projects. After the joint piloting program ended, P2 actively promoted its new technological solution for medical implants.

Upon customers' positive reactions, P2, together with its clients, tested 3D printed medical implants to establish the right parameter setting and printing positions. Following this fabrication testing and product qualification, customers soon placed orders for 3D printed implants, shortly leading to a capacity shortage. In hindsight, P3 lamented "It seems that you can only do this successfully together with your customer unless you elect to work in the prototype market where finished product properties are less important."

Supplier support. When implementing new technology, supplier support often is critical. Van Dijk (2015) identified vendor support as one of the factors influencing AM adoption. When innovating, suppliers can be a source of external knowledge (West & Bogers, 2014). All participant organizations involved their suppliers during the AM implementation process. C2 and C4 limited its use of suppliers to companies with solid reputations for supplying powders suitable for use in AM processes to their markets. C2 limited the involvement of suppliers to the delivery of the AM equipment. C1, on the other hand, worked closely with a 3D modeling company and various AM equipment suppliers to create their 3DP business model.

Theme 3: Embed Additive Manufacturing Technology

Embedding AM in the organization by adopting the technology and adjusting the firm's business model emerged as the third theme, supported by two subthemes: business model innovation and technology adoption. Considering the substantial difference in work preparation, operation, and technology of AM compared to traditional subtractive technologies, embedding this novel technology requires new employee skills. Integrating an immature technology such as AM is a substantial challenge for SMEs (Zanetti et al., 2016). Furthermore, those firms need to adapt their existing business model to adjust for the different opportunities that AM offers or should establish a separate business unit or legal entity to nurture the new technology.

Business model innovation. According to the University of Paderborn in Germany, adopting AM mostly does not radically alter companies' business models (University of Paderborn, n.d.). Building on Cotteleer and Joyce (2014), Steenhuis and Pretorius (2017) argued that companies adopting AM either improve their existing products by using their existing business model, create a new model, or do both. Accordingly, four types of AM adoption could be distinguished: (a) stasis or equilibrium, (b) supply chain evolution, (c) product evolution, and (d) business model evolution, see Table 1

Table 1

Types of Additive Manufacturing Adoption

Type	I	II	III	IV
Characteristic	Equilibrium	Supply chain evolution	Product evolution	Business model evolution
Product change	Low	Low	High	High
Supply chain change	Low	High	Low	High
Goal	Profit and cost reduction	Creating a profitable new market	Profit through higher performance and growth	Growth and innovation
Company	C2, C3, C4	C1		C4

In the equilibrium phase, firms adopt AM to create more complex or customized products, either following customer demand or as a first step towards an enhanced business model or the creation of unique products (Cotteleer & Joyce, 2014). This stage represents a relatively low-risk approach (Steenhuis & Pretorius, 2017). C2 and C3 operate in this phase. C1 is an example of a firm adopting AM to create a new supply chain for low volume or customized products, parallel but separate from their existing one. An example of a firm adopting AM in the product evolution phase is General Electric, making the complex fuel nozzles for their LEAP jet engines with 3DP equipment, thereby reducing the number of parts from 20 to one, also reducing weight with 20% (Conner et al., 2014).

Type 4 AM adoption currently is not widespread. Rare examples are: 3D printed five-story concrete buildings made by Chinese company Winsun (Kothman & Faber, 2016), the 3D printed, highly customized, chocolate products made by Miam Factory, a spin-off from the Belgium University of Leuven (Schofield & Colville, 2017). Katjes' Magic Candy Factory is another rare example of a company that created a new business model using a 3D printer to make customized gel candy (Noort, Van Bommel, & Renzetti, 2017).

When C4 took a strategic decision to implement AM, they quickly discovered that no suitable AM technology existed for printing ceramic materials. Hence, they decided to develop this technology themselves. When their prototype machine became more mature, C4 started selling this equipment, parallel to using it for producing 3D printed ceramic products. Later, C4 also developed metal 3D printers, based on the same technological concept as used for the ceramic printers. By morphing from a ceramic products contract manufacturer to a 3DP equipment manufacturer, C4 can be considered a type IV AM adoption company.

All participating firms occupied a similar position in their supply chains: that of a contract manufacturer. This position did not change after implementing AM (except for the 3DP equipment C4 developed and sells, next to their contract manufacturing activities). Nevertheless, when zooming into their manufacturing activities, business model differences between these organizations can be noticed. C1 accepts all 3DP activities, subcontracts design, metal printing, and finishing activities in addition to its core logistics activities. C2, C3, and C4 all offer finishing and inspection/testing activities but avert taking responsibility for design activities, as they did before AM implementation.

Contrary to Amshoff et al. (2015), the participant firms demonstrated a non-transformational approach to business model innovation. It could be argued that C1 ignited a non-market disruption, competing against nonconsumption (Christensen & Raynor, 2003). Possibly, this risk-averse approach is caused by the significant cost business model innovation requires (Rayna & Striukova, 2016). For incumbent firms often no other choice exists than trial and error when it comes to business model innovation, and this heuristic process comes at a significant cost, particularly in case a new business model is developed in parallel (Rayna & Striukova, 2016). P2 confirmed, “additive manufacturing was added as an additional competence.” In a hybrid model, traditional manufacturing is combined with AM capability, offering advantages like faster production, high finish quality, or less assembly (Ford & Despeisse, 2016) and minimizing disadvantages (Newman et al., 2015). The participants’ choice for such a model seems prudent. Notwithstanding, P2 also warned that AM could "cannibalize existing products" by eventually replacing the conventional manufacturing methods. P3 noticed the new 3DP activities attracted new customers who subsequently also showed interest in their traditional machining activities.

Separate business unit. Christensen and Raynor (2003) advised organizations fighting or creating disruptive innovations to establish an autonomous business unit. Such an organization does not have to be physically located elsewhere or have different shareholders. Merely, the idea is to establish a unit free of corporate culture, overhead, processes, and cost structure.

Sometimes, the choice where to establish the new technology does not result from deliberate strategic decisions but out of practical circumstances. C1 did not create a separate business unit but decided to establish the 3DP exploration lab in their *value-added logistics* and not in their *logistics solutions* organization as the leadership wanted P1, a senior manager of this organization, to lead this initiative. C2 did not set up a separate business unit either but embedded the AM capabilities in their medical division. However, resulting from the fast growth of AM-related orders, C2 procured more AM equipment, and C2's shareholders have decided to set up a separate organization for 3DP only, serving all companies in their holding. Sometimes, the separate unit eventually becomes or overflows the primary organization (Christensen & Raynor, 2003). Creating this stand-alone entity may be a possibility for C2. P4 believed that this feeder firm could benefit more from its parent company, especially their knowledge of traditional machining. Therefore, P4 forecasted that C4 would eventually merge back into its parent organization. Markides (2006) described such approach as: creating feeder companies to colonize new markets the central group later may take over.

Building 3DP knowledge. Following the acquisition of 3DP equipment and the initial pilot phase, firms need to integrate these new resources into their organizations (Cremona, Mezzenzana, Ravarini, & Buonanno, 2016). AM production know-how is a source of competitive advantage (Cremona et al., 2016; Holzmann, Breitenecker, Soomro, & Schwarz, 2017). Production know-how can be obtained from suppliers or established in-house. Wolff (2016) highlighted the different skillset AM engineers need, compared to traditional metal workers: computer literacy, metallurgy, gas flow, laser melting, mechanics, or coordinate measuring systems. Following the further adoption of 3DP technology, increasing demand for a competent industrial workforce emerged (Simpson et al., 2017).

Highly competent workforce. When implementing AM into an existing manufacturing organization, companies require employees with different expertise (Oettmeier & Hofmann, 2016b). Kothman and Faber (2016) argued that more automation of traditional manufacturing activities leads to a reduced need for lower-skilled workers whereas a disruptive technology as AM requires highly skilled employees. P2 explained the effect on their workforce

> The team handling 3D printing here did not exist three years ago. They are all new people. They all have master's degrees. People who were involved with the development of 3D printers. Previously, we had workers educated at vocational level but are now they are all university-educated people.

The General Electric Corporation, that already adopted 3DP on a large scale, published a report on how advanced manufacturing technology affects the workforce of the future (Soltesz, Rutkofsky, Kerr, & Annunziata, 2016). Soltesz et al. posited that the disruptions by innovations, such as AM, have resulted in workers having outdated competences will become redundant. Notwithstanding, these disruptive innovations also create new job opportunities at a more strategic or creative job level (Soltesz et al., 2016).

Upon further proliferation of 3DP technology, more jobs may return from offshored locations to higher wage countries, as products can be manufactured closer to the point of consumption (Brennan et al., 2015; Soltesz et al., 2016). However, a scarcity of qualified AM engineers is expected (Van der Zee et al., 2015). P1 even believed that “there’s going to be a trade war … over people who are good at 3D modeling and engineering, because that is the new gold.”

Production know-how. During the piloting phase of the new technology, the participant firms accumulated knowledge about the particulars of work preparation and manufacturing parameter settings for 3D printed products. Additionally, some of the participant firms emphasized the importance of understanding general customer requirements that remain unchanged despite the new manufacturing technique: avoiding cross-contamination of materials, the oxygen content of final products, using anti-static floors, or product and process certification. Cremona et al. (2016) argued that such know-how is one of the most valuable intangible assets that a company may possess. As early adopters of AM technology, the participant firms have established a substantial competitive advantage that will be difficult to replicate by later entrants.

Application to Professional Practice

The findings of this study could be of advantage to industry leaders and manufacturing managers who are contemplating to adopt AM in their business models. The results of the study may also work as a catalyst for increased awareness for manufacturing firm leaders who have not yet considered the opportunities and threats AM technology presents to their organizations.

Managers of some small to medium-sized light and high-tech manufacturing firms in the Netherlands identified the opportunities 3DP offered for competitive advantage. When companies operating in niche markets identify new business opportunities, such as AM, they need to take risks and assign their limited resources to their pursuit (Ford & Despeisse, 2016). The participant companies used various methods for identifying the size and attractiveness of the opportunities and marketplace. This research also revealed strategies that these SMEs used to probe AM and their considerations for business model innovation and methods to embed the newly adopted technology in their organizations.

The participating company's decision-makers have taken a leap of faith; some of them may soon be among industry leaders. The knowledge of AM that these firms acquired might also lead them to create innovative business models. Later adopters of this technology will have substantial work catching up. This research presented details of the strategies some small to medium-sized manufacturing firms in the Netherlands used for the implementation of a revolutionary manufacturing technique.

Implications for Social Change

The results of the study may contribute to positive social change through providing strategies that managers could utilize to adopt AM technology, thereby increasing local employment opportunities, improving the environment, and enhancing healthcare for the prosperity of local and global citizens. For example, the use of AM has implications for positive social change in the medical sector.

By using AM technology, the costs of certain medical treatments are reducing. Furthermore, the technological possibilities of AM enable manufacturing of porous medical implants enhancing bone ingrowth (Taniguchi et al., 2016; Wang et al., 2016), thereby supporting the speedier recovery of patients. These medical enhancements benefit society as a whole.

Industry leaders may also gain a clearer understanding of the effects of 3DP on local employment. Simpson et al. (2017) believed that a lack of skilled labor to operate AM equipment inhibits further diffusion of this technology. This study revealed that operators of traditional manufacturing equipment could be educated to control AM equipment. However, setting-up AM machines and work preparation activities require employees with higher education, up to doctoral level. The implications for social change include giving manufacturing managers a better understanding of the effects of 3DP on their workforce.

At the time of this study, AM was not widely adopted nor displaced industries or caused substantial reshoring of manufacturing activities. The trend of reshoring of low-volume and complex products was visible but not as significant as Brennan et al. (2015) predicted. AM has the potential to accelerate the reshoring process, but it will require substantial redesign of products to reap the full benefits of AM (Kianian et al., 2016) and such redesigns could cost up to 30 times the cost of the original design (Hällgren, Pejryd, & Ekengren, 2016). Reshoring manufacturing activities to developed countries, such as The Netherlands, will increase local labor opportunities.

Another benefit of AM is weight optimization and minimization of resource usage (Burkhart & Aurich, 2015). Redesigned products, using AM, are lighter than the original items, produce less waste, and most firms reuse all non-sintered metal powders. This reduced use of natural resources is a benefit to society, worldwide.

Recommendations for Action

Because AM impacts existing supply chains, manufacturing locations will move, consumers will become producers, production activities will be reshored, different workforce competencies will be required, and traditional designs will change. The impact of this technology should not be underestimated. Therefore, managers and policymakers need to start considering the disruptive effects of 3DP to their business and to society.

I am a regular speaker at conferences to raise awareness of the strategic importance of AM technology to businesses and offer the audience suggestions for 3DP adoption strategies. I am also a lecturer, and I intend to use this study to develop teaching materials to educate students. Furthermore, I will provide the organizations that participated in this research a summary of the study. Finally, together with a professor at a Dutch university, I will convert this study into academic papers with the ultimate intent of having them published in reputable journals.

Recommendations for Further Research

This exploratory case study intended to examine what strategies managers of light and high-tech manufacturing industries in the Netherlands used for adopting AM in their firms' business models. A research limitation was the relatively small sample size, the type of participating firms, and limiting the geographic boundaries to three provinces of a small country like the Netherlands. Therefore, I recommend further research on a larger participant size. Furthermore, as the diffusion of AM technology is spreading, conducting a similar study using quantitative or mixed research methods could reveal more insights into strategies used for adopting 3DP. Further research could also include AM service organizations, or manufacturing firms in other provinces or countries.

Reflections

For some time, I was contemplating pursuing a doctoral degree in business administration, but because my work made me move to seven countries in 8 years, the circumstances were not optimal. Furthermore, I understood the importance of researching a topic that I was passionate about, so I would retain interest and motivation for many years during this study. While based in China, I had a meeting with a consultant who asked me what my firm *was doing with this disruptive innovation called 3D printing.* Because I did not know much about this topic, I began investigating 3DP and quickly became fascinated with the technology and its business opportunities.

On visits to suppliers, I inquired what strategies they were developing for using AM, and I learned that they all dismissed the technology. Therefore, I explored the subject further and discovered that companies often did not see the relevance of AM, and when they did, often did not know where to start. I realized that the implementation of AM was a contemporary topic of strategic importance to business practice. After thorough market research, I enrolled in the Walden University DBA program, which became the most significant intellectual, time-management, and perseverance challenge that I have ever encountered. Nevertheless, the doctoral study has been a been a rewarding process in which I honed existing capabilities, learned new skills, and gained greater knowledge about conducting research, the theory of disruptive innovation, the opportunities and treats of AM, and the challenges of adopting this novel technology.

I had no preconceived ideas about the study topic and kept an unbiased view throughout my research. Instead, I relied on pre-existing research on the subject and the data that I collected. However, when reading vast amounts of academic and popular literature, I realized what a revolutionary technology I was researching, and I gained more appreciation for scholars who labeled 3DP a *disruptive innovation*. Based on my research, I theorize that AM will change the way we design, make, and sell products. The use of AM will have effects similar to the Internet; a technology with little diffusion 20 years ago, but that meanwhile has changed our way of life, companies' business models, and enabled the rise of the most significant firms in the world.

Conclusion

AM, or 3DP, emerged as a disruptive technology affecting multiple organizations' business models and supply chains. Some first mover companies have already implemented AM. From this multiple case study, three major themes emerged: identify business opportunities for AM technology, experiment with AM technology, and embed AM technology. The findings showed that manufacturing firm managers adopted 3DP as a result of the potential competitive advantage that the technology offers instead of an attempt to disrupt the marketplace. All participant companies identified markets where customers would value some of the unique characteristics of AM: either low volume, high complexity, customized products, or items requiring short delivery times. Mostly, those customers operated in niche markets. The participants in this study conducted extended periods of probing 3DP, either individually or jointly with customers, suppliers, partners, or government agencies.

The findings of this study revealed the importance of managers to first understand the opportunities of 3DP and second, to conduct thorough market research to identify potential customers and marketplaces interested in products made with AM technology. Next, managers should plan for an extensive experimentation period required to learn how to operate this technology and to understand the products for which the use of AM could be attractive. Finally, managers need to select the appropriate business model for adoption of the new technology and recruit operators and engineers with the right skills and education, different from their existing workforce.

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Appendix A: Interview Protocol

Step	Action	Script
General introduction	Introduction of the student and the study	Thank you for meeting me today. My name is Robert Martens, and I am a student at Walden University. This interview part of my doctoral study of Business Administration. The topic of my research relates to the strategies managers of light and high-tech manufacturing companies in the Netherlands used for adopting additive manufacturing into their business models.
Consent form	Assure the consent forms are signed	I have sent you an informed consent form. Do you have any questions or concerns about this form? If not, could you please sign it?
Interview process	Explain the interview process	In this interview, I will ask you seven open-ended questions. Please feel free to answer in your own words and add more information you deem relevant. I will also ask you probing questions and summarize your answers for verification. I will audio record this interview for easier transcription and take notes. You and your company will not be named in my study, and all information that you share with me will remain confidential. The interview will take approximately 60 to 90 minutes.
Other data	Request for additional data	In addition to the interview, what company documents can you share with me that might be useful for my study?
Interview questions	Ask the following seven interview questions	1. How did additive manufacturing technology enable new opportunities for your business? 2. What alternative strategies did you consider when you were confronted with the emergence of additive manufacturing? 3. How were your suppliers' additive manufacturing capabilities of influence to your decisions? 4. How did the emergence of additive manufacturing affect your firm's existing business model? 5. What strategies has your organization developed to adopt additive manufacturing in your business model? 6. What strategic considerations did you have for establishing/not-establishing a separate business unit to operate additive manufacturing? 7. What additional information would you like to share about strategies for adopting additive

		manufacturing?
Member checking	Explain the member checking process	After the interviews are transcribed, I will schedule a follow-up call with you. In this call, I will ask you some follow-up questions regarding the interview and the documents you shared with me. These member checking interviews will take about 30 minutes.
Wrap up	Close and thank the participant	Thank you for your time and support. Do you have any questions or comments?